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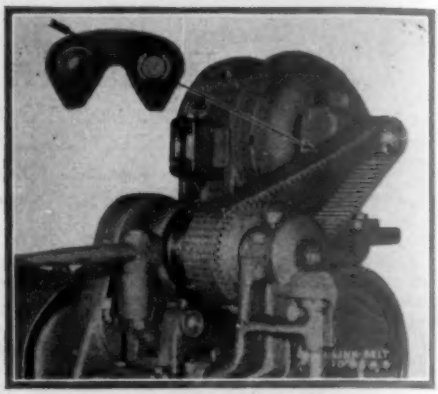

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THE DISTURBANCE OF SUPRA-CONDUCTIVITY BY MAGNETIC FIELDS AND CURRENTS. THE HYPOTHESIS OF SILSBEE.*

BY

W. TUYN, Ph.D., and H. KAMERLINGH ONNES, Ph.D., Sc.D.

Emeritus Director, Physical Laboratory, University of Leiden;
Honorary Member of the Institute, Franklin Medalist.

NOTE.—While the manuscript for this paper was on the ocean in transit from Leiden to Philadelphia, news of the death of Dr. H. Kamerlingh Onnes appeared in the daily papers. His death takes a brilliantly successful figure out of the world of experimental science, and deprives the realm of scholarship of an important contributor. THE EDITOR.

§1. THE interesting property of supra-conductors, that below the vanishing-point temperature their supra-conductivity can be disturbed by raising the current-density, is treated in a previous paper;[1] afterwards it was found that supra-conductivity can also be disturbed by a magnetic field, of which the intensity is determined by the temperature and by the directions of the field with regard to the windings of the wire.[2]

* Communicated by Doctor Onnes and published as Communication No. 174a from the Physical Laboratory at Leiden: Further experiments with liquid helium, AA.

[1] Leiden Comm. No. 133a (1913).

[2] Leiden Comm. No. 139f (1914).

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When the war caused a delay in the investigation of supra-conductivity at Leiden, Silsbee, at Washington, increased the interest in the further inquiry into these properties with his hypothesis that " the threshold value of the current is equal to that value, at which the magnetic field, caused by the current, is equal to the magnetic threshold value." [3]

The importance of Silsbee's hypothesis is clear as its correctness would make the current threshold value disappear. Though some questions of secondary importance still remain, the experiments are in agreement with the hypothesis.

It was only with a few data that Silsbee could test his hypothesis. For tin, but not for lead, the relation between the threshold values of the current and the magnetic field seemed to exist, whereas for mercury there were no magnetic measurements. More convincing than the comparison of the two threshold values were the calculations, which show that at the critical current-strength the self-magnetic field at the surface of mercury wires of different diameters in this case was a more constant magnitude than the current-density, it being supposed that measurements belonging to the same temperature are compared with each other; Silsbee obtained the same for wires of tin and lead.[4]

Since the measurements with helium after the interruption due to the war and its consequences have been taken up again, many data have been collected, not exclusively in order to test the hypothesis of Silsbee, yet suitable to it. In the first place much time has been spent in order to determine for lead, tin and indium the dependence of the magnetic threshold value on temperature; further in a single case the critical current-strength for thallium, lead and tin wires has been determined, and finally the measurement of resistances, of which the self-magnetic field is decreased in a very particular way, has been carried out.[5]

[3] F. B. SILSBEE, *Jour. Wash. Acad. of Sci.*, **6**, 597, 1916; Sc. Pap., Bur. of Stand., **14**, No. 307, 1917.

[4] The terms, " self-magnetic field," " critical current-strength " and " critical magnetic field," are self-explanatory.

[5] One of us made use of the contents of this paper for his Leiden thesis for the doctorate. W. Tuyn, " Weerstandsmetingen in vloeibaar helium," Diss., Leiden, 1924. This thesis having been published in Dutch and being therefore not easily accessible, we have treated the subject independently here.

A. THE MAGNETIC THRESHOLD VALUE.[a]

§2. *The Magnetic Fields; the Influence of the Terrestrial Magnetic Field.*—In order to obtain the magnetic fields we used four different coils. The intensity of the field for a point with coördinate z, on the axis, has been calculated from the formula:

$$H_z = 4\pi ni \cdot \frac{1}{2}\left\{\frac{z}{\sqrt{R^2+z^2}} - \frac{z-l}{\sqrt{R^2+(z-l)^2}}\right\} = 4\pi ni \cdot Az,$$

o and l being the coördinates of the extremities of the coil.

The first two coils have such dimensions that they fit exactly around the air-vessel of the helium cryostat.

(1) Coil *B;* length, 25.5 cm.; diameter, 13.7 cm.; total number of windings, 140; $A_{z=\frac{1}{2}l} = 0.881$.

(2) Coil *W;* length, 18.8_5 cm.; diameter, 13.6–16.4 cm.; total number of windings, 8×68, in eight layers; $A_{z=\frac{1}{2}l} = 0.783$.

The last two coils have smaller dimensions for the purpose of bringing them *into* the helium cryostat; they are constructed as follows: We coiled enamelled copper wire on a penholder, paraffined the windings to keep them together and, after having pulled away the penholder, tied them together, for the purpose of rigidity.

(3) Coil *H;* length, 63 mm.; diameter, 7 mm.; total number of windings of the first layer, 100, of the second, 94; $A_{z=\frac{1}{2}l} = 0.993$; the middles of the two layers coincide.

(4) Coil *K;* length, 75 mm.; mean diameter of the two layers, 9 mm.; total number of windings, 260; $A_{z=\frac{1}{2}l} = 0.994$.

The intensities of the currents through the coils have been measured with the aid of Weston ampere-meters.

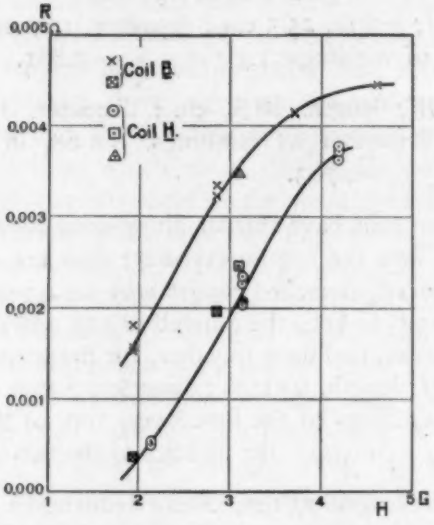
The fields of the coils are not homogeneous. By making the length of the tubes on which the resistance wires are coiled as short as possible, and by putting the tubes in the middle part of

[a] At a definite temperature and intensity of the current through the conductor there was ordinarily meant by "the magnetic threshold value" the intensity of the magnetic field that brought back the first measurable resistance; in this communication, however, we mean by it the intensity of the field, that causes in the conductor half of the resistance, which can come back at the end-field.

the coils, we tried to remove this difficulty. The inhomogeneity is annoying because each turn of the wire is found in a magnetic field of a different intensity, and so a definite current through the magnetic coil brings back in each turn a different portion of the resistance. We have introduced the mean field intensity, that is the intensity which is the mean of the intensities on the part of the axis taken up by the resistance; with the aid of the preceding formula this can be calculated.

Finally the fields have to undergo a correction for the exist-

FIG. 1.



ence of the terrestrial magnetic field. For measurements at temperatures only little below that of the vanishing-point, this correction is proportionally large. We have determined the influence of the terrestrial magnetic field on the supra-conductivity of *Sn*–1922–*M* at $T = 3°.72$ K. ($p_{\text{helium}} = 455.8$ mm. Hg). We used the coils *B* and *H;* by reversing the current their field could be directed parallel or opposite to that of the earth. With both field directions we investigated the relation between resistance and magnetic field—neglecting that of the earth—and obtained two curves, which by moving them along the axis of the field intensities can be made to agree. Thus we find by moving

this over about 0.8 gauss, the influence of the vertical component of the terrestrial magnetic field, even quantitatively. This behavior is explained by Fig. 1.

It is difficult to separate wholly the transverse and longitudinal effect,[7] each resistance wire always having more windings. For the wires coiled transversely the coiling in a spiral is a source of errors, of the wires coiled longitudinally the bent ends of the long coils are perpendicular to the magnetic field. The transverse effect is stronger than the longitudinal effect.

§3. *Measurements.*—We have given the results of our measurements in the following tables. *The data of the field intensities have only been corrected for the intensity of the terrestrial field when this is particularly mentioned; before adjusting a new magnetic field, the former one was nearly always totally annihilated.*

In each table we give first the vapor tension of the helium bath and the temperature at which the measurement takes place. The temperature has been calculated from the vapor pressure by means of the formula of Leiden Comm. No. 147b (33, 1915[8]); most of these pressure observations on the closed or open mercury manometer we owe to G. P. Nijhoff, assistant of the laboratory. Then we give the intensity of the current with which the resistance has been measured. Concerning the magnetic fields we give for A—see the formula of §2—the maximum and the minimum values, that is, the values that this magnitude has at those places in the coil where, with a symmetrical position, the middle and the outmost turns of the resistance lie. The ratio of the two is a measure for the inhomogeneity of the field. Also we give the average of A and the formula, by which the mean field intensities have been calculated.

For the determination of the resistances we measured the potential differences at the extremities of a known and an unknown resistance, connected in series, by the aid of a Diesselhorst compensation apparatus, free of thermo-electromotive forces, supplied by O. Wolff. From the potential differences we calculated resistances as if Ohm's law were valid.

[7] About these effects see Leiden Comm. No. 139f, §3, 1914.

[8] See also footnote 1 of Leiden Comm. No. 167a, 4, 1923.

We measured the returning of the resistance only for tin, lead and indium; for mercury and thallium such measurements have not yet been done. We have restricted ourselves to a single case for graphical representation.

1. TIN.

TABLE I.

Sn–1922–M, Transverse.

The resistance has been constructed from wire extruded from "Kahlbaum" tin. The wire has been bifilarly wound on a glass tube in about sixty windings; paraffined paper and silk thread served here for insulation. Diameter = 0.19 mm.

p_{helium} = 455.5–455.8 mm. Hg. T = 3°.72 K.

Measuring current = 4.0 mA.

Coil *B*.

$A_{max.}$ = 0.881, $A_{min.}$ = 0.878, ratio = 0.996.

A_{mean} = 0.880. H_{mean} = 6.07 i (i in amp.).

Coil *H*.

$A_{max.}$ = 0.993, $A_{min.}$ = 0.984, ratio = 0.991.

A_{mean} = 0.992. H_{mean} = 40.32 i (i in amp.).

Date.	Mean Field Intensity.		$R_{Sn-1922-M}$.
	With Coil *B*.	With Coil *H*.	
April 6, 1922		17.6 gauss	0.00448 Ω
		17.4	0.00447
		13.2	0.00440
April 28, 1922	9.71 gauss*		0.00445
April 6, 1922		8.58	0.00441
		6.08	0.00437
April 28, 1922	5.03		0.00445
	4.12		0.00415
		3.77	0.00370
	3.27		0.00328
		2.72	0.00216
	2.43		0.00196
	2.36		0.00162
		1.73	0.00052
	1.52		0.00037

*With the measurements on April 28, 1922, the vertical component of the terrestrial magnetic field (0.4$_2$ gauss) has been taken in account; its influence here was large. The field intensities on April 6, 1922, being stronger than the critical ones, the terrestrial field could then be neglected.

TABLE II.

Sn–1922–A, Transverse.

The resistance has been constructed from bands of tin, obtained by rolling out extruded tin wire. Material is "Kahlbaum" tin. The band is wound semi-bifilarly* on glass and insulated by paraffin. Thickness = 0.0$_5$ mm.

$T = 3°.42$ K.

Coil *H*.

$A_{max.} = 0.993$, $A_{min.} = 0.977$, ratio = 0.984.

$A_{mean} = 0.989$. $H_{mean} = 40.2_2\, i$ (i in amp.).

Mean Field Intensity.	December 8, 1922. p_{helium} = 310.4–310.7 mm. Hg. Measuring Current = 4.0 mA. $R_{Sn-1922-A}$.	January 19, 1923. p_{helium} = 310.6–312.0 mm. Hg. Measuring Current = 4.0 mA. $R_{Sn-1922-A}$.
60.3 gauss		0.0056$_2$ Ω
56.3		0.0056$_0$
52.3		0.0055$_8$
48.3	0.0055$_3$ Ω	0.0055$_4$
46.2$_5$	0.004$_6$	0.005$_3$
44.2	0.001$_2$	0.002$_9$
43.2		0.000$_5$
42.2	0.000$_3$	0.0000$_0$
40.2	0.0000$_0$	0.0000$_0$

*We mean by this that the windings have been wound inductively, but with the layers in opposite direction.

TABLE III.

Sn–1922–I, Transverse.

The resistance has been constructed from wire, extruded from "Kahlbaum" tin. This wire is wound bifilarly on glass and insulated by paraffin and silk. Diameter = 0.1$_5$ mm.

p_{helium} = 309.8–310.1 mm. Hg. $T = 3°.41_5$ K.

Coil *W*.*

$A_{max.} = 0.770$, $A_{min.} = 0.678$, ratio = 0.88c.

$A_{mean} = 0.732$. $H_{mean} = 33.5_7\, i$ (i in amp.).

February 7, 1923. Mean Field Intensity.	Measuring Current = 2.0 mA. $R_{Sn-1922-I}$.	Measuring Current = 4.0 mA. $R_{Sn-1922-I}$.	Measuring Current = 6.5 mA. $R_{Sn-1922-I}$.
53.7 gauss	0.0018$_0$ Ω		0.0017$_5$ Ω
50.4	0.0017$_6$	0.0017$_5$ Ω	0.0017$_5$
47.0	0.0017$_5$	0.0017$_2$	0.0016$_9$
43.6	0.001$_5$	0.001$_n$	0.000$_9$
40.3		0.000$_3$	0.000$_2$
36.9		0.0001$_7$	0.000C$_9$
35.3	0.0001$_1$		
33.6	0.0001$_0$	0.0000$_4$	0.0000$_6$
30.2			0.0000$_2$

*In these measurements by a misunderstanding the middle of the longitudinal axis of the resistance did not coincide with that of the coil.

TABLE IV.

Sn–1922–V, Longitudinal.

The resistance has been constructed from wire, extruded from "Kahlbaum" tin. This wire has been wound bifilarly, stretched on mica; paraffin and silk served for insulation. Diameter = 0.2$_4$ mm.

Coil *W*.

p_{helium} = 309.8–310.1 mm. Hg. T = 3°.41$_8$ K.

$A_{max.}$ = 0.783, $A_{min.}$ = 0.678, ratio = 0.866.

A_{mean} = 0.749. H_{mean} = 34.3$_8$ i (i in amp.).

February 7, 1923. Mean Field Intensity.	Measuring Current = 2.0 mA. $R_{Sn-1922-V}$.	Measuring Current = 4.0 mA. $R_{Sn-1922-V}$.	Measuring Current = 6.4 mA. $R_{Sn-1922-V}$.
51.5 gauss	0.0018$_8$ Ω	0.0018$_7$ Ω	0.0018$_9$ Ω
49.8	0.001$_8$	0.001$_7$	
48.1	0.0009$_5$	0.001$_1$	0.001$_5$
44.7		0.0000$_8$	0.0001$_5$
41.2	0.0000$_2$	0.0000$_3$	0.0000$_7$

TABLE V.

Sn–1922–A, Transverse.

Dec. 8, 1922. p_{helium} = 119.0 mm. Hg. T = 2°.81$_8$ K.*

Jan. 19, 1923. p_{helium} = 118.2–118.8 mm. Hg. T = 2°.81$_4$–2°.81$_7$ K.

Measuring current = 4.0 mA.

Coil *H*.

$A_{max.}$ = 0.993, $A_{min.}$ = 0.977, ratio = 0.984.

A_{mean} = 0.989. H_{mean} = 40.2$_2$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1922-A}$.
Jan. 19, 1923	160.9 gauss	0.0056$_3$Ω
Dec. 8, 1922	160.9	0.0056$_1$
Jan. 19, 1923	148.8	0.0056$_4$
Dec. 8, 1922	140.8	0.0055$_8$
Jan. 19, 1923	136.7$_5$	0.0056$_0$
	132.7	0.0055$_9$
	128.7	0.0055$_0$
Dec. 8, 1922	124.7	0.0054$_8$
Jan. 19, 1923	124.7	0.0053$_6$
Dec. 8, 1922	120.7	0.002$_2$
Jan. 19, 1923	120.7	0.001$_4$
Dec. 8, 1922	116.6	0.000$_8$
Jan. 19, 1923	116.6	0.000$_2$
Dec. 8, 1922	112.6	0.0000$_7$
Jan. 19, 1923	112.6	0.0000$_9$

* The thousandths of a degree serve in this and the following tables only in order to demonstrate the constancy of the helium bath; they have no more meaning.

TABLE VI.

Sn–1922–A, Transverse.

p_{helium} = 40.4–40.5 mm. Hg. T = 2°.31$_8$–2°.31$_4$ K.

Measuring current = 4.$_9$ mA.

Coil *H*.

$A_{max.}$ = 0.993, $A_{min.}$ = 0.977, ratio = 0.984.

A_{mean} = 0.989. H_{mean} = 40.2$_2$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1922-A}$.
Jan. 30, 1923.....	241.3 gauss	0.0056$_8$ Ω
	201.1	0.0056$_2$
Dec. 8, 1922.....	201.1	0.0055$_8$
Jan. 30, 1923.....	186.0	0.0055$_8$
	181.0	0.005$_6$
Dec. 8, 1922.....	181.0	0.005$_4$
	177.0	0.004$_7$
	173.0	0.001$_1$
	168.9	0.000$_2$
Jan. 30, 1923.....	164.9	0.000$_2$
Dec. 8, 1922.....	164.9	0.0000$_8$
	162.9	0.0000$_0$

TABLE VII.

Sn–1922–I, Transverse.

p_{helium} = 40.7 mm. Hg. T = 2°.31$_6$ K.

Measuring current = 4.$_9$ mA.

Coil *W*.*

$A_{max.}$ = 0.783, $A_{min.}$ = 0.758, ratio = 0.968.

A_{mean} = 0.776, H_{mean} = 35.5$_9$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1922-I}$.
Feb. 7, 1923.....	202.9 gauss	0.0017$_4$ Ω
	199.3	0.0017$_5$
	195.8	0.0017$_5$
	192.2	0.0017$_5$
	181.5	0.0016$_9$
	178.0	0.001$_4$
	174.4	0.0001$_7$
	170.8	0.0001$_1$
	167.3	0.0000$_8$

*The middle of the longitudinal axis did not coincide with that of the coil.

TABLE VIII.

Sn–1922–V, Longitudinal.

p_{helium} = 40.7 mm. Hg. T = 2°.31$_8$ K.

Measuring current = 4.$_0$ mA.

Coil *W*.

$A_{max.}$ = 0.783, $A_{min.}$ = 0.678, ratio = 0.866.

A_{mean} = 0.756. H_{mean} = 34.6$_7$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1922-V}$.
Feb. 7, 1923...	201.1 gauss	0.0019$_1$ Ω
	197.6	0.0019$_0$
	194.2	0.001$_7$
	190.7	0.001$_5$
	187.2	0.001$_2$
	183.8	0.000$_9$
	180.3	0.0000$_8$
	176.8	0.0000$_5$
	173.4	0.0000$_3$
	156.0	0.00000

TABLE IX.

Sn–1923–I, Longitudinal.

The resistance was constructed from wire extruded from "Kahlbaum" tin. The wire was wound bifilarly lengthwise on a glass tube of such thickness that it could be placed in the coil H. Diameter = 0.1$_4$ mm.

p_{helium} = 39.9–40.0$_8$ mm. Hg. T = 2°.30$_8$–2°.30$_9$ K.

Measuring current = 4.$_0$ mA.

Coil *H*.

$A_{max.}$ = 0.993, $A_{min.}$ = 0.975, ratio = 0.982.

A_{mean} = 0.989. H_{mean} = 40.2$_8$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1923-I}$.
Oct. 23, 1923...	221.1 gauss	0.0010$_8$ Ω
	211.0	0.0010$_4$
	193.0	0.0010$_5$
	186.9	0.0010$_2$
	184.9	0.0010$_1$
	180.9	0.0001$_1$
	176.9	0.0000$_8$
	160.8	0.00000

TABLE X.

Sn–1922–A, Transverse.

$p_{\text{helium}} = 11.7_8$ mm. Hg. $T = 1°.85$ K.

Measuring current = 4.0 mA.

Coil *H*.

$A_{max.} = 0.993$, $A_{min.} = 0.977$, ratio = 0.984.

$A_{mean} = 0.989$. $H_{mean} = 40.2_2\, i$ (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1922-A}$.
Jan. 30, 1923...	241.3 gauss	$0.0056_2\ \Omega$
	225.2	0.0055_6
	221.2	0.0055_6
	217.2	0.005_2
	213.2	0.002_9
	209.1	0.000_9
	205.1	0.0000_9
	203.1	0.0000_0

TABLE XI.

Sn–1922–I, Transverse.

$p_{\text{helium}} = 4.6$ mm. Hg. $T = 1°.52$ K.

Measuring current = 4.0 mA.

Coil *W*.*

$A_{max.} = 0.783$, $A_{min.} = 0.758$, ratio = 0.968.

$A_{mean} = 0.776$. $H_{mean} = 35.5_3\, i$ (i in amp.).

Date.	Mean Field Intensity.	$R_{Sn-1922-A}$.
Feb. 7, 1923 ...	249.1 gauss	$0.0017_1\ \Omega$
	245.6	0.0016_2
	242.0	0.001_3
	238.5	0.001_0
	231.3	0.000_3
	224.2	0.0001_4
	213.5	0.0000_8

*In these measurements by a misunderstanding the middle of the longitudinal axis of the resistance did not coincide with that of the coil.

2. LEAD.

§4. Because of the high vanishing-point temperature of lead, we must use, even at the helium boiling-point fields of some hundreds of gauss, to disturb the supra-conductivity of the metal. Because of the position of their vanishing-point temperature, the measurements with lead and with tin resistances complement each other in this case. To our regret we have not been able to make measurements below $T = 3°.77$ K.

TABLE XII.

Pb–1923–I, Transverse.

The resistance has been constructed from wire, extruded from "Bureau of Standards" lead. This wire is wound bifilarly on glass and insulated by paraffin and silk. Diameter = 0.1$_9$ mm.

$p_{\text{helium}} = 834$ mm. Hg. $T = 4°.30$ K.

Measuring current = 4.$_0$ mA.

Coil *W*.

$A_{max.} = 0.783$, $A_{min.} = 0.766$, ratio = 0.978.

$A_{mean} = 0.778$. $H_{mean} = 35.6_8\, i$ (i in amp.).

Date.	Mean Field Intensity.	$R_{Pb-1923-I.}$
March 12, 1924.	606.6 gauss	0.0034$_8$ Ω
	570.9	0.0033$_4$
	553.0	0.0032
	535.2	0.0028
	517.4	0.0013
	499.5	0.0001$_2$
	492.4	0.0000$_4$
	463.8	0.0000$_0$
	428.2	0.00000

TABLE XIII.

Pb–1923–I, Transverse.

$p_{\text{helium}} = 750$–753 mm. Hg. $T = 4°.18$ K.

Measuring current = 4.$_0$ mA.

Coil *W*.

$A_{max.} = 0.783$, $A_{min.} = 0.766$, ratio = 0.978.

$A_{mean} = 0.778$. $H_{mean} = 35.6_8\, i$ (i in amp.).

Date.	Mean Field Intensity.	$R_{Pb-1923-I.}$
Oct. 23, 1923...	570.9 gauss	0.0031 Ω
	553.0	0.0028
	535.2	0.0014

TABLE XIV.

Pb–1923–III, Longitudinal.

The resistance has been constructed from wire, extruded from "Bureau of Standards" lead; this wire has been wound bifilarly on mica; paraffin and silk served for insulation. Diameter = 0.1$_8$ mm.

p_{helium} = 750–753 mm. Hg. T = 4.°18 K.

Measuring current = 4.$_0$ mA.

Coil *W*.

$A_{max.}$ = 0.783, $A_{min.}$ = 0.774, ratio = 0.988.

A_{mean} = 0.781. H_{mean} = 35.8$_2$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Pb-1923-III}$.
Oct. 23, 1923...	626.9 gauss	0.002$_5$ Ω
	608.9	0.002$_0$
	573.1	0.000$_2$
	537.3	0.0000

TABLE XV.

Pb–1923–I, Transverse.

p_{helium} = 460.7–460.8 mm. Hg. T = 3°.73 K.

Measuring current = 4.$_0$ mA.

Coil *W*.

$A_{max.}$ = 0.783, $A_{min.}$ = 0.766, ratio = 0.978.

A_{mean} = 0.778. H_{mean} = 35.6$_8$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{Pb-1923-I}$.
March 12, 1924.	595.9 gauss	0.0005$_8$ Ω
	574.4	0.0000$_4$
	570.9	0.0000$_2$
	535.2	0.00000

§5.

3. INDIUM.

TABLE XVI.

*In–1922–A, Transverse.**

p_{helium} = 119.3–119.5 mm. Hg. T = 2°.81$_5$–2°.82$_0$ K.

Measuring current = 4.$_0$ mA.

Coil *K*.

$A_{max.}$ = 0.993, $A_{min.}$ = 0.975, ratio = 0.982.

A_{mean} = 0.988. H_{mean} = 43.0$_8$ i (i in amp.).

Date.	Mean Field Intensity.	$R_{In-1922-A}$.
Jan. 30, 1923...	90.4 gauss	0.1568$_1$ Ω
	86.1	0.1562$_8$
	81.8	0.13$_6$
	77.5	0.10$_7$
	73.2	0.07$_5$
	68.9	0.05$_9$
	64.6	0.01$_9$
	60.3	0.009$_6$
	56.0	0.003$_6$
	51.7	0.001$_3$
	47.4	0.0002$_4$

*Particulars about this resistance are to be found in Leiden Comm. No. 167a, 1, 1923.

TABLE XVII.

In–1922–A, Transverse.

p_{helium} = 40.3–40.5 mm. Hg. T = 2°.31$_2$–2°.31$_4$ K.

Measuring current = 4.$_0$ mA.

Coil *K*.

$A_{max.}$ = 0.993, $A_{min.}$ = 0.975, ratio = 0.982.

A_{mean} = 0.988. H_{mean} = 43.0$_8$ i (i in amp.).

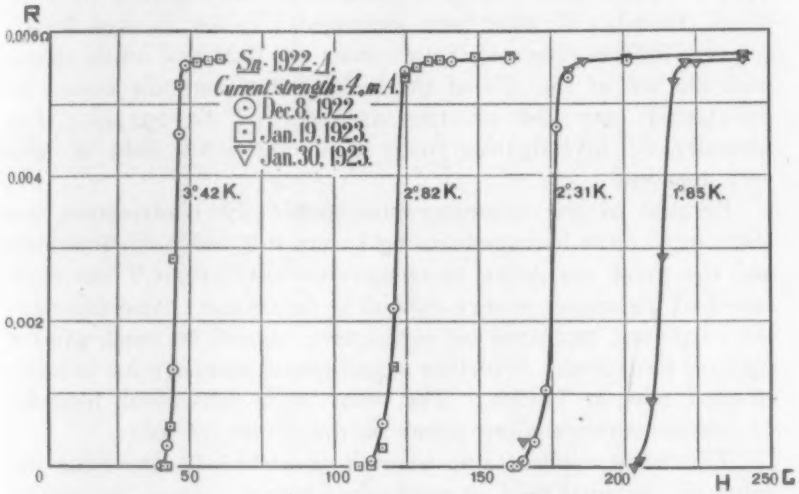
Date.	Mean Field Intensity.	$R_{In-1922-A}$.
Jan. 30, 1923...	146.4 gauss	0.1562$_7$ Ω
	142.1	0.1562$_8$
	137.8	0.13$_2$
	129.2	0.05$_9$
	116.3	0.04$_0$

For the graphical representation we restrict our choice to the tables belonging to *Sn–1922–A*. See, therefore, Fig. 2.

§6. *Remarks.*—The inhomogeneity of the field is one of the causes that the measurements only approximately give the right

relation between field and resistance. We could conclude that the cause of the difference obtained between the initial field and the final field does not wholly lie in this inhomogeneity. In the initial field we suppose that the first measurable resistance, in the final field that the whole residual resistance is restored [9]; here we have to calculate with "mean field intensities" or more easily with the current intensities in the coil belonging to it. Let us suppose that a homogeneous field brings back the residual resist-

FIG. 2.



ance with a jump at *one* field intensity H_k, the critical one, then for our measurements—with an inhomogeneous field—this intensity will be reached for the middle resistance windings at the initial current, for the outer at the final current through the coil; at each temperature the degree of inhomogeneity, such as follows from the relation of the A's, will then determine the intensity of this current difference. Then the following must hold:

$$H_k = A_{max.} \cdot 4\pi n i_{beginning},$$
$$= A_{min.} \cdot 4\pi n i_{end}.$$

The difference, measured by us, being greater than the calcu-

[9] By this is not meant the residual resistance at $T = 0°$ K., but the resistance, which for tin and indium is about equal to that just above the vanishing-point temperature.

lated difference,[10] showed at a measuring current of 4.0 mA that a restoring of the resistance did not take place suddenly. The intensity of the measuring current seems, however, to have influence, but from the experience gained with the longitudinal effect it would be premature to conclude a total restoration with a jump at one field intensity.

The quick, almost sudden, increase of the resistance of the longitudinal tin wires with increasing field intensity is astonishing. When we set out graphically the observations of *Sn*–1923–*I* (Table IX) this strikes one immediately. The fields in which *Sn*–1922–*V* have been measured (Tables IV and VIII) are very inhomogeneous; if we correct the final and initial values with the aid of the *A*'s of the tables mentioned, the curves of *Sn*–1922–*V* are just as steep as those of *Sn*–1923–*I*. The necessity of investigating with a homogeneous field is here very apparent.

Because of the inhomogeneous field (the contrivances for obtaining a more homogeneous field were still under construction) and the great sensibility to temperature-oscillations,[11] the right aspect of the curves is very difficult to determine. Also the number of points, measured on each curve, should be much greater than we measured. A further experimental investigation is being effected now at Leiden. The want of a theoretical formula, to indicate corresponding points on the curves, is seen.

This want appears also when it is wished to determine the value of the final field in particular, because above the critical values the resistance increases with increasing magnetic field. This also applies generally for non-supra-conductors.[12] Here we

[10] This can be found from Fig. 2 for *Sn*–1922–*A*. Here $H_{mean} = A_{mean} \cdot 4\pi ni$ has been set out. To find this difference we must, however, have for the initial value:

$$H_{beginning} = \frac{A_{max.}}{A_{mean}} \cdot 4\pi ni_{beginning} = 1.004\, H_{mean\ (beginning)}$$

for the final value:

$$H_{end} = \frac{A_{min.}}{A_{mean}} \cdot 4\pi ni_{end} = 0.988\, H_{mean\ (end)}.$$

For all four curves H_{end} is stronger than $H_{beginning}$.

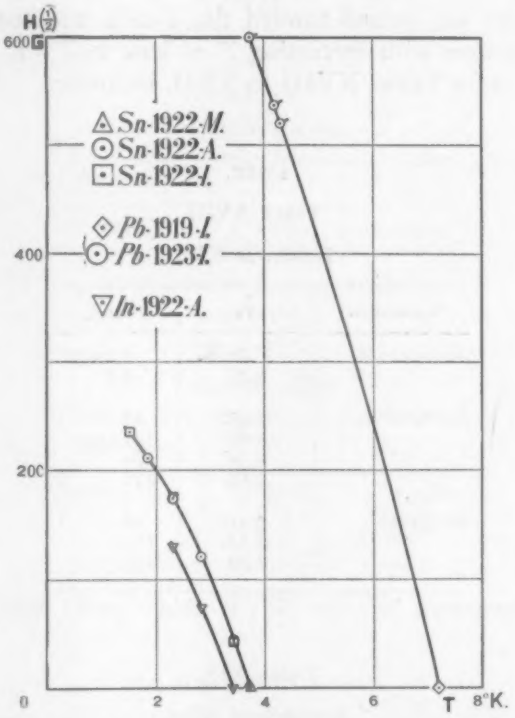
[11] For which see also Leiden Comm. No. 167a, §2, 1923.

[12] Leiden Comm. No. 142b (1914).

touch at the same time the question of the type of the transition from supra-conductivity to normal conduction.

The intensity of the initial field is also difficult to determine. Practically there is the difficulty of the varying thermo-effects, theoretically that of the definition of the initial field. If we choose for this the field in which the *first measurable* resistance is restored, it has only the same meaning for different resistances

FIG. 3.



when with decreasing field intensity the resistance approaches quickly, but not asymptotically, to zero. The form of the curves and the comparison of current with magnetic threshold values [13] indicate a very rapid decrease.

§7. *The Dependence of the Threshold Value on Temperature.*—From each table we can derive the magnetic field in which the resistance is half restored. *We did this with the aid of graphs*

[13] See §11 of this paper.

and tried to bring into account the correction for the inhomogeneity of the field; this correction can be considerable. By choosing this mean value, $H_{(\frac{1}{2})}$, we avoided the difficulties of indicating the final field and besides had corresponding points on the different curves.[14]

Fig. 3 represents the results for the transverse effect for lead, tin and indium. The value of T for $H=0$ is that of the vanishing-point. The three lines show a great conformity. Their concave sides are turned toward the T-axis and the curvature becomes stronger with decreasing T, at least to $T=1°.5$ K. The results follow in Tables XVIII to XXII, inclusive.

1. TIN.

TABLE XVIII.

Transverse Effect.

Resistance.	T.	$H_{(\frac{1}{2})}$.
Sn–1922–*M*.	3°.74 K.	0 gauss
	3.72	2.5
Sn–1922–*A*.	3.42	44
	2.82	121
	2.31	174
	1.85	212
Sn–1922–*I*.	3.41$_5$	42
	2.31$_5$	175
	1.52	235

TABLE XIX.

Longitudinal Effect.

Resistance.	T.	$H_{(\frac{1}{2})}$.
Sn–1922–*V*.	3°.41$_5$ K.	46 gauss
	2.31$_5$	180
Sn–1923–*I*.	2.31	182

[14] As already stated, this value is different from the "magnetic threshold value," formerly defined; see footnote 6.

2. LEAD.

TABLE XX.

Transverse Effect.

Resistance.	T.	$H_{(\frac{1}{2})}$.
Pb–1919–*I*.	7°.2 K.	0 gauss
Pb–1923–*I*.	4.30	520
	4.18	537
	3.73	601

TABLE XXI.

Longitudinal Effect.

Resistance.	T.	$H_{(\frac{1}{2})}$.
Pb–1923–*III*.	4°.18 K.	595 gauss

3. INDIUM.

TABLE XXII.

Transverse Effect.

Resistance.	T.	$H_{(\frac{1}{2})}$.
In–1922–*A*.	3°.41 K.	0 gauss
	2.82	74
	2.31	130

The results from Table XVIII can be represented by the formula:

$$H_{(\frac{1}{2})} = -20.1\,T^2 + 280.7.$$

For further investigation we set out graphically the values of $H\left(\frac{1}{2}\right)$ and T^2 for the transverse effects of tin, indium and lead. For tin and indium we obtained straight lines, which were nearly parallel. (Fig. 4.) For lead we have but few points, but these may very well lie on a straight line with that point agreeing with the vanishing-point temperature, it may be that the inclination of this line differs from that of the other lines.

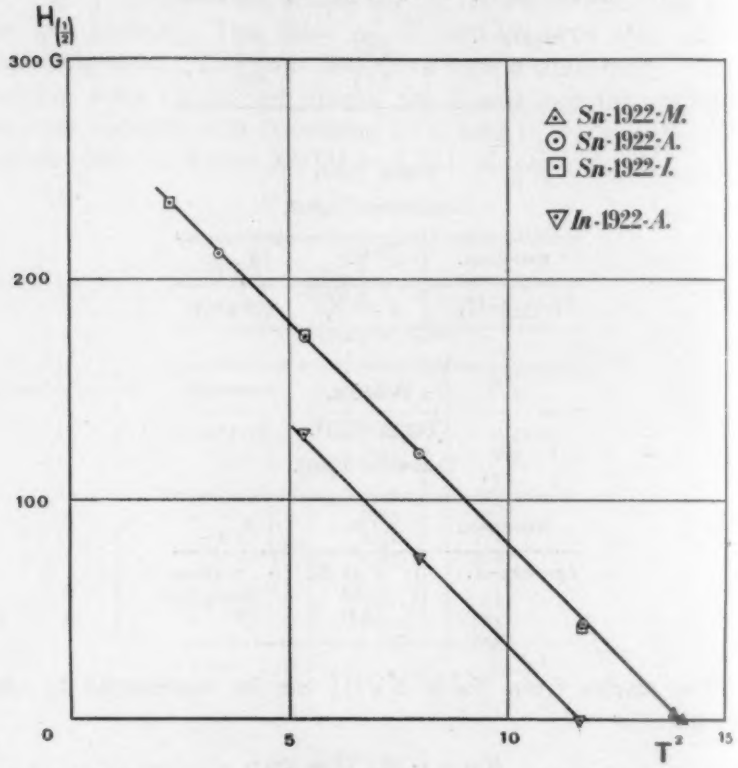
We regret that we have not been able to make measurements

for lead below $T = 3°.8$ K.[15]; these and those above the boiling-point of helium are very important.

From the observations of the transverse effect of tin and indium, we may derive:

$$H_{(\frac{1}{2})} = -hT^2 + H_{0\,(\frac{1}{2})},$$

FIG. 4.



$H_{0(\frac{1}{2})}$ being the value of $H_{(\frac{1}{2})}$ at $T = 0°$ K. If T_s is the vanishing-point temperature, then

$$H_{0(\frac{1}{2})} = hT^2_s,$$

by which the formula becomes

$$H_{(\frac{1}{2})} = h(T^2_s - T^2).$$

[15] There are, for lead, previous measurements at $T = 2°$ K., Leiden Comm. No. 139f (1914), but the fields were produced with the Weiss magnet, and with these field intensities working with wire-coils is preferable to that with the magnet.

This simple formula gives—at least with the measurements as yet made—the relation between the magnetic threshold value and the temperature.[16] A completing investigation must follow. A comparison of the magnitude h of the different supra-conductors must not be omitted. Besides, relations for the initial and final fields will also be necessary, if they do not coincide when using infinitely small measuring currents and homogeneous fields.

§8. The hypothesis of Silsbee can not be proved by magnetic measurements alone. The simple relation obtained seems to show that the magnetic field will be of primary importance for the disturbing of supra-conductivity.

B. THE CURRENT THRESHOLD VALUE.[17]

§9. The determination of the current threshold value has been tried at some temperatures. The method was to measure the potential difference at the extremities of the resistance by means of a Diesselhorst compensation apparatus, supplied by O. Wolff, the current intensity through the resistance being increased; the only difference from the other resistance measurements is that much stronger currents were used. In order to be able to ascertain the first restored potential difference, it is desirable to use a galvanometer more sensitive than we possessed. Because of their danger to the apparatus, the measurements take very much time; at a restoring of the resistance such a violent heat development occurs that the wire may melt. Oscillations in the temperature of the bath are, even with the most accurate arrangements, inevitable; the small rise at an oscillation is sometimes sufficient to cause considerable damage. The heat, which is

[16] From theoretical considerations, P. W. Bridgman derives

$$T^3 - T^3_s = cH^2,$$

Jour. Wash. Acad. of Sci., 11, 455, 1921. In pursuance of the considerations of Bridgman, Professor Keesom made röntgenograms of lead placed in liquid hydrogen and helium; these indicate for the greater part an unchanged structure of this metal. Rapport au IVème Conseil-Solvay par H. Kamerlingh Onnes (1924), Leiden Comm. Suppl. No. 50a, 14, 1924.

[17] If by the current threshold value the intensity of that current is meant, which restores at the extremities of the resistance the smallest, still measurable potential difference, this definition is not complete without making definite the amount of the potential difference and the dimensions of the resistance.

developed in a wire at a restoring of the resistance, is shown by a sudden ebullition of the helium bath.[18]

§10. *Measurements.*[19]

1. TIN.

A piece of tin wire is at both extremities joined to lead wires, and to this the four lead extremities; the wires have been extruded from material "Kahlbaum." In spite of the two lead-tin welds a potential difference at the extremities of the resistance below the vanishing-point temperature of tin was not noticeable when using 4.0 mA.

TABLE XXIII.

Sn–1922–F.

$2r = 0.2_8$ mm. $\pi r^2 = 0.03_1$ mm.^{2}.

Date.	p helium in mm. Hg.	T.	Threshold Current in Amp.	Density of the Threshold Current in amp./mm.^{2}.	$\frac{2i}{r}$ in $\frac{\text{amp.}}{\text{mm.}}$
March 2, 1922	257	3°.28 K.	2.2	70	44
	71	2.56	> 2.25	> 72	> 45

2. LEAD.

TABLE XXIV.

Pb–1919–I and *–B.**

Pb–1919–I.
$2r = 0.1_4$ mm.
$\pi r^2 = 0.01_6$ mm.^{2}.

Pb–1919–B.
$2r = 0.4_7$ mm.
$\pi r^2 = 0.1_7$ mm.^{2}.

May 28, 1920.	Threshold Current in Amp.		Density of the Threshold Current in amp./mm.^{2}.		$\frac{2i}{r}$ in $\frac{\text{amp.}}{\text{mm.}}$	
T.	*Pb*–1919–*I.*	*Pb*–1919–*B.*	*Pb*–1919–*I.*	*Pb*–1919–*B.*	*Pb*–1919–*I.*	*Pb*–1919–*B.*
7°.07 K.	0.10$_7$	0.4$_6$	6.$_7$	2.$_7$	3.0	4.0
7.0$_4$	1.1$_3$	> 3.0$_9$	70.$_5$	> 17.$_3$	31.$_8$	> 26.$_1$
7.1$_9$	0.3$_5$–0.7$_9$	0.3$_5$–1.0$_1$	20.$_1$–49.$_4$	1.$_8$–5.$_9$	9.$_3$–20.$_3$	2.$_9$–8.$_3$
Mean 7°.07 K.	0.6$_9$	> 1.3$_3$	37.$_3$	> 8.$_0$	16.$_9$	> 12.$_0$

* With these resistances the vanishing-point temperature of lead was determined; see Leiden Comm. No. 160b (1922). The temperatures, mentioned in Table XXIV, are determined in the manner sketched in that communication.

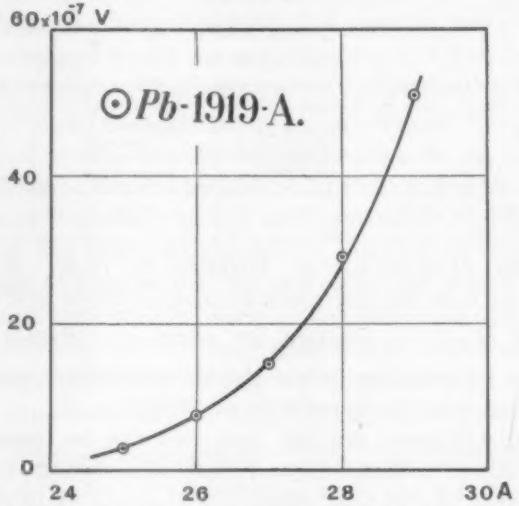
[18] See also Leiden Comm. No. 133a, 17, 1913.

[19] Current threshold values of mercury, tin and lead, already published, have been collected by Silsbee in Sc. Pap., Bur. of Stand., 14, No. 307, 1917; those of thallium in Leiden Comm. No. 160a, Table III, 1922.

These results are hardly perfect. The temperature oscillations in the helium vapor cryostat are perhaps still too great for this kind of measurement; the heat development in the connecting wires may be of influence here.

With another resistance *Pb*–1919–*A*, wound bifilarly, constructed from extruded wire of lead "Kahlbaum," we determined at $T = 4°.21$ K. and increasing current intensity, the restoring

FIG. 5.



potential difference at the extremities. The results can be found in Table XXV; see also Fig. 5.

TABLE XXV.

Pb–1919–A.

$p_{\text{helium}} = 764$ mm. Hg. $T = 4°.21$ K.

Strength of the Current.	Potential Difference.
20 A.	0. 10^{-7} V.
25	3
26	7.5
27	14.5
28	29
29	51

When the measurements with 29 A. were almost ready, the scale disappeared out of the field of vision of the telescope. The

wire was heated by the restoring of the resistance and with fatal results. On dismounting the cryostat, the lead wire was found to have melted through; the lead-globules at the defective place proved it; at another place the silk thread which held the lead turns in place was singed. The diameter changed over the whole wire from 0.2_8 mm. to 0.2_7 mm.; the minimum thickness near the place, melted through, was not much smaller than at other places. From Fig. 5 we derive for the threshold value an intensity of 24 A.

TABLE XXVI.

Pb–1919–A.

$l = 1186$ mm. $2r = 0.2_7$ mm. $\pi r^2 = 0.05_9$ mm.^{2}.

Date.	T.	Threshold Current in Amp.	Density of the Threshold Current in amp./mm.^{2}.	$\frac{2i}{r}$ in $\frac{\text{amp.}}{\text{mm.}}$
March 12, 1920.	4°.21 K.	24	407	356

§11. *The Hypothesis of Silsbee.*—In order to test this hypothesis we consider the wires as being straight and circular of section. If $H = \frac{2i}{r}$ is constant for wires of different diameters at the same temperature, when threshold currents pass through them, this supports the hypothesis of Silsbee.

Our measurements are but few, but can be compared with those that Silsbee collected from former observations at Leiden.[20] Table XXIV shows, in spite of the bad accuracy, $\frac{2i}{r}$ at $T = 7°.0_7$ K. for *Pb*–1919–*I* and –*B*, wires of different diameters, as being much more constant than the density of the threshold currents. At $T = 4°.21$ K. (see Table XXVI) the value of $\frac{2i}{r}$ for *Pb*–1919–*A* agrees with that of the table of Silsbee for other resistances; also agreement between the intensities of the threshold currents or that of their densities does not exist here. Further, the observations published in Leiden Comm. No. 160a, Table III, 1922, prove that at the same temperature also for *Tl*–1916–*VIII* and –*IX*—noting the difference in diameter—the values of $\frac{2i}{r}$ are equal to each other. These measurements support the hypothesis of Silsbee.[21]

[20] F. B. SILSBEE, Sc. Pap., Bur. of Stand., **14**, No. 307, 1917.

[21] See for another supposition, however, the last part of Leiden Comm. No. 160a, §5, 1922.

For the relation between the threshold values of current and magnetic field we have still to compare the value of $H = \frac{2i}{r}$ from the threshold current with the magnetic threshold value. Here we meet with difficulties. The current as well as the magnetic threshold values have been determined as the magnitudes, with which the first measurable potential difference was restored. In those two cases the wire under discussion does not need to be in the same condition. Let us keep, therefore, a moment to Ohm's law. We determine the magnetic field that restores the potential difference mentioned with a current of only 4 mA through the wire; in the meantime the threshold current, which does this also, often has an intensity of many amperes. The potential differences being equal to each other, the restored resistance must be much greater in the first case than in the last. Ohm's law does not hold here, but we can provisionally adhere to a formula $E = i \times r$, r not being constant at the same temperature. Further, it does not seem unreasonable to suppose that a supra-conductor is *then* in the same state at each temperature when it has the same resistance, and not when one measures the same potential difference at its extremities, whatever law may hold here. Then we may expect—even when the hypothesis of Silsbee holds—no agreement between the magnetic threshold value and $H = \frac{2i}{r}$ from the threshold current[22]; the calculated value of H will always be the smallest. *That we still find a rather good agreement indicates a sudden, at least very rapid, restoring of resistance in the wire with increasing magnetic field;* then it is also clear, why for these measurements with wires of different lengths we still find concordant results. That we can combine Silsbee's hypothesis with the nature of this restoring is fortunate. Further, it is to be expected that the heat development in the wire causes a disturbance at great current intensities; therefore the calculated H has to be smaller than that from magnetic measurements.

Now the data. For *Sn*–1922–*F* follows from Table XXIII at $T = 3°.28$ K. for $H = \frac{2i}{r}$ 44 gauss; the magnetic threshold value is 56. For *Pb*–1919–*A* (Table XXV) at $T = 4°.21$ K. is

[22] That the values of $H = \frac{2i}{r}$ of different wires at the same temperature are nearly equal to each other can yet be understood; the i's differ here less.

$H = \frac{2i}{r}$ 356 gauss, thus in agreement with the numbers of the table of Silsbee [23]; the magnetic threshold value is 430. The magnetic threshold values of thallium and mercury have not yet been determined; if we observe the inclination of the lines for indium and tin in Fig. 5, and if we make that of thallium equal to them, then also at $T = 1°.4$ K., $H = \frac{2i}{r} = 30$ gauss remains below the magnetic threshold value of this metal.[24]

These measurements are not in disagreement with the hypothesis of Silsbee.

C. FURTHER EXPERIMENTS.

§12. *Experiment with Indium Wires, Wound in Different Ways.*—To test the hypothesis of Silsbee some further experiments were made. As such we consider first of all the observation mentioned in Leiden Comm. No. 167a, §2, 1923, that the vanishing-point temperature of an indium wire wound bifilarly, of which the windings lay close together, was higher than that of a wire of which the distance of the coilings was greater; this was ascribed to a difference in influence of the magnetic field of the current on the nearest coilings.

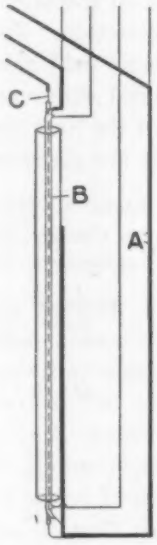
§13. *The Supra-conductivity of a Tin Cylinder, Influenced by the Magnetic Field of a Current along the Cylinder Axis.*—Silsbee's hypothesis will be adaptable as soon as experiments show that a resistance which ceased to be supra-conductive by exceeding the threshold current becomes again supra-conductive by affixing an external magnetic field, which weakens the inner magnetic field of the threshold current in each point. On arranging such experiments we sought in the first place to obtain similar fields. This was obtained better with the following apparatus than with the indium resistances, already mentioned.

A tin band B was wound upon a glass tube, through which a copper wire was pulled; the whole resembles a hollow cylinder with copper axis. Through B, cooled below its vanishing-point temperature, we send currents stronger than the threshold current, so that the supra-conductivity is disturbed, and we measure a potential difference at the extremities of B. Through the copper axis we pass in opposite direction a current of which the

[23] See this table in F. B. Silsbee, Sc. Pap., Bur. of Stand., **14**, No. 307, 1917.
[24] Leiden Comm. No. 160a, Table III, 1922.

magnetic field and that of the current through B weaken or neutralize each other. If the threshold current holds its power for disturbing the supra-conductivity at its magnetic field, then it must be possible to restore the supra-conductivity in B—in spite of the strong currents. For our measurements [25] we used two such pieces of apparatus of very different diameters. Of the first, G_1, the length of the tin cylinder was 10 cm., its thickness 0.09_4 mm., its outer diameter 5 mm., of the second, G_2, con-

FIG. 6.



structed by the chief of the technical staff, G. J. Flim, and reproduced in Fig. 6, these measurements were, respectively, 10 cm., 0.09_3 mm. and 0.8 mm. The part of the copper wire that in the first apparatus was surrounded by the glass, covered with tin, is replaced in the second apparatus by a lead wire C of 0.1_7 mm. diameter, pulled through the glass capillary on which the tin band was wound; at the measurements this wire remains supra-conductive. At equal current intensities in the second instrument stronger fields are used. In order to deform these fields as little as possible the horizontal part of the connecting wire A is 2.5 cm. The number of the connecting wires decreases by

[25] On one of the measuring days we had the help of W. van Gulik, assistant of the laboratory.

one—and by this the heat supply—by soldering one of these wires of B to A, as Fig. 6 shows. For the form of the extremities of the tin band see the same figure; this lip-form has been chosen for the uniform current-distribution along the part of the tin band to be measured. The wide glass tube given in Fig. 6 serves for protecting the tin band.

With both pieces of apparatus the disappearance of the resistance of the tin cylinder is observed with falling temperature, first when a current of 2.50 A. only passed through the cylinder, and then when besides a current of the same intensity passed along the cylinder axis in opposite direction. Though in the second series of measurements no magnetic field exists at the outer surface of the tin cylinder, the potential difference, measured then, always appears greater than that of the first series, belonging to the same temperature. These results are given in Table XXVII.

TABLE XXVII.

Tin Cylinder, G_1.

Date. March 12, 1924. p_{helium} in mm. Hg.	T.	$i = 2.50$ A. Exclusively through the Cylinder. Potential Difference.	$i = 2.50$ A. through the Cylinder and Back along the Axis. Potential Difference.
479.4	3°.76 K.	515.10^{-7} V.	
478.0			512.10^{-7} V.
474.1			495
473.5		479	
469.7		422	
467.8			380
464.1		244	
462.7			191
461.1		124	
459.2		57	
459.0			51
456.5			8
453.8	3.71$_8$	0	

§14. The following experiment was made at the next helium day. A current of 2.0 A. was passed through the tin cylinder G_2 cooled below the vanishing-point temperature and then through the lead cylinder axis currents of different intensities in the opposite direction. This was repeated at three different temperatures. The potential differences, measured at the extremities of the cylinder, pass through a minimum which is even zero at the lowest temperature. The results of these measurements, given in Table XXVIII, are represented by Fig. 7.

TABLE XXVIII.

Tin Cylinder G_2.

Date. April 17, 1924. p_{helium} in mm. Hg.	T.	Current through the Tin Cylinder.	Current through the Lead Cylinder Axis in Opposite Direction.	Potential Difference.
425.7–426.4	3°.66 K.	2.0 A.	0.0 A.	114.10^{-7} V.
		2.0	0.0	83
		2.0	0.5	12
		2.0	1.0	12
		2.0	1.5	150
		2.0	1.8	401
		2.0	2.0	741
		2.0	2.0	676
		2.0	3.2	2157
		2.0	4.0	2518
430.2–430.5	3.67	2.0	0.0	463.10^{-7}
		2.0	1.0	20
		2.0	2.0	1033
439.4–439.6	3.69	2.0	0.0	1399.10^{-7}
		2.0	0.7	168
		2.0	1.0	257

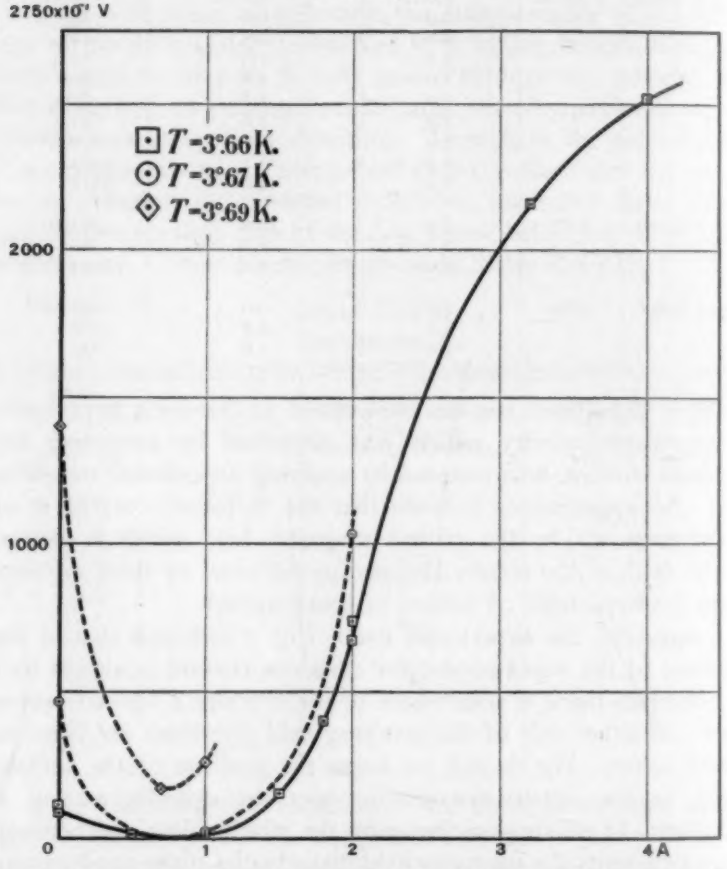
As is demanded for the correctness of Silsbee's hypothesis, the supra-conductivity which was disturbed by exceeding the threshold current, was restored by applying an external magnetic field. All experiments indicate that the threshold current is of importance only by the critical magnetic field which it causes. On the faith of the results obtained up till now, we think we may accept the hypothesis of Silsbee as being correct.

Concerning the experiment itself, Fig. 7 indicates that at the restoring of the supra-conductive state one current is almost half the other; so there is somewhere in the cylinder a surface where $H = 0$; on either side of the resulting field directions are opposite to each other. We do not yet know the position of the surface $H = 0$, as the density-distribution over the cylinder section is unknown. If we suppose that with the relation obtained between the two currents the magnetic field disturbs the supra-conductivity as little as possible, such experiments can perhaps show something about this distribution.

The penetrating of the magnetic field of the central current in the cylinder is accompanied by induction currents, which "persist" as long as the field is not changed. It is desirable to investigate if in some cases these currents can influence the results.

§15. *The Micro-residual Resistance.*—After the discovery of supra-conductivity the idea of "micro-residual resistance" [26] has been introduced; as an upper limit of this there was indicated the resistance calculated from the quotient of the minimum perceptible potential difference and the current threshold value, as if Ohm's

FIG. 7.



law were valid. One was the more sure to have an upper limit when the calculation was applied to a case where the current remained below the value at which any potential difference at all (10^{-8} volt) was observed at the ends of the conductor. In this way with a small coil in a layer only 1 cm. thick containing, over

[26] Leiden Comm. No. 133, 30, 1913.

a length of 1 cm., 1000 windings of lead wire, which remained superconductive even when it was charged with 0.8 amp., was deduced for lead at 1°.8 K. a certainly too high upper limit, *i.e.*, that $0.5.10^{-10} = R1°.8\ \text{K.}/R273°\ \text{K.}$ This low value showed the way to obtain the persistent currents which proved a more powerful means for the investigation of the micro-residual resistance than the threshold current and turned temporarily off the attention from the latter. As to the explication of this phenomenon the question had been considered if it could be explained by the resistance originated by the own field of the current. But the answer had been negative because according the analogy it had to be accepted that the magnetic additive resistance increased regularly with the field. No trace of such an additive resistance had been found below the threshold current. Again in the case of the coil treated above, the own field had been even some 600 gauss without originating any trace of resistance. It was not before the startling discovery of the threshold field was made, showing that at a field of 1000 the coil recovered ordinary resistance, that the argument taken from these observations had to be dropped and the question of the explanation of the threshold value of the current had to be considered in the light of the new information. Silsbee has had the happy idea to take this to hand. He has drawn attention to the fact that, when the intensity of the current is raised sufficiently, the effect of the magnetic field of the current comes into play and would give an apparent micro-residual resistance, even if the real resistance of the supra-conductor was rigorously zero.

We can try to obtain a relation for the limit of the apparent micro-residual resistance, that will be found for the different supra-conductors. If the minimum perceptible potential difference is V, the threshold current i and the limit of the apparent micro-residual resistance R, then by definition

$$R = \frac{V}{i}.$$

Take i equal to the value from $H = \frac{2i}{r}$ in which H is the threshold value; this implies, after the considerations of §11, an almost discontinuous disturbance of the supra-conductivity. Further suppose, just as for $H_{\left(\frac{1}{2}\right)}$, the validity of

$$H = h_1 (T^2_3 - T^2),$$

then

$$R = \frac{2V}{rH} = \frac{2V}{h_1 r(T_s^2 - T^2)}.$$

So the relation for R is indeed rather complicated, as it was to be expected.[27] It gives a qualitative explication of the observed phenomena of the threshold current by magnetic apparent micro-residual resistance.

It is a pleasure to us again to acknowledge gratefully the benefit which the Leiden laboratory has derived for the work with liquid helium in general from the increase of its stock of helium gas by the welcome gift of the American Navy sent to Professor Onnes by Admiral Griffin in 1919.

Effects of Weather on Mortars and Cements. (Bulletin, National Lime Association.)—Acute weather conditions in the present winter have emphasized the cold weather problems of the contractor and builder. Mortar is one of the most important. To find a mortar that will fill the requirements for compressive and tensile strengths, retain its workability under severe conditions and yet be economical, has been one of the most important questions in the field.

Eight lime and Portland cement mixes and four bricklayers' cements were recently tested at the University of Wisconsin for shear, tensile and compressive strengths after curing in warm and cold storage. From these tests a lime-cement mortar composed of one part cement, two parts lime and nine parts sand was recommended for winter use. Strength, workability and economy requirements are all fulfilled by this 1 : 2 : 9 mortar.

This mix is low in cost. The materials are readily available in all sections of the country, and may be purchased under standard specifications which insure absolute uniformity. With building operations carried further into cold weather with profit to the contractor, convenience to the owner and an extended season of employment for the workmen, the findings of the tests conducted at the University of Wisconsin are most timely. H. L.

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[27] We can easily give an example of the application of this relation. Take the values for *Pb*–1919–*A* from Table XXVI. Then is $V = 1.10^{-5} V$, $r = 0.13_5$ mm., $T_s = 7°.2$ K. and $T = 4°.2$ K.; for h_1 we take 15 (this number is yet doubtful). Now $R = 3.10^{-10}\Omega$. The direct measurements give $R = 4.10^{-10}\Omega$. So is $\frac{R}{R_0} = \frac{3.10^{-10}}{3.7} = 0.8.10^{-10}$. Further applications, as the determination of h_1 for mercury from former measurements, we omit; for this their accuracy is too small.

SPACE CHARACTERISTICS OF ANTENNÆ.*

BY

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INTRODUCTION.

THE directional characteristics of loops and various antennæ on the ground or horizontal plane have been given considerable attention, less frequently have the space characteristics of certain antennæ operating at or above their fundamental or at certain harmonics and of loop antennæ been discussed. Very little has, however, been said or written regarding the equations governing space characteristics or the field intensities which they represent, their space coördinates, and the effects of these fields on variously located and orientated receiving antennæ, especially as facilities for studying such fields have been limited. In the following various basic assumptions are made in order to simplify conditions, but these do not cause errors in excess of the accuracy of measurements made by the writer during the past six years. The assumptions made are that the antenna length is very small compared with the wave-length, so that the effect of phase displacement becomes practically negligible; that the distance from the transmitter to the receiver, which we will call unit distance, is large compared with the wave-length, but so small with respect to the earth that the curvature of the same may be neglected; that the earth when it comes into question is to be assumed a perfect conductor; and that at the distances concerned the effect of waves refracted or reflected by upper atmospheric layers may be considered negligible. It has fortunately been found that Doctor Burstyn, of Vienna, has made a similar study in the *Jahrbuch der drahtlosen Telegraphie* and that many formulæ developed by him substantially correspond with and therefore substantiate formulæ developed below.

GENERAL.

It is well known that radio waves travel from a given source in all directions with the velocity of light and therefore that they form rapidly expanding spheres provided they are not absorbed

* Communicated by the Author.

or reflected, just as do light waves; similarly the intensity of the radio or light waves will not be equal at all points of a sphere. It is evident, for instance, that the light intensity emitted from a straight filament is greatest along the great circle which lies in a plane perpendicular to the filament and that it is a minimum at the two points or poles which lie along the axis of which the filament forms a part. It is known further that the radio wave consists of two physical fields, namely, the electrostatic field and the electromagnetic field, both of which are at right angles to one another as well as to the direction of wave travel or propagation, and therefore that both fields are tangental to the sphere of reference. In any case, knowing the direction of wave propagation, it is only necessary to determine, let us say, the electrostatic field both with regard to its position in space and its intensity, in order to obtain therefrom the electromagnetic field which is at right angles thereto, as stated above, and whose intensity is determined by the formula $\mathfrak{E} = 300\ H$, where $\mathfrak{E}$ is the electrostatic field intensity measured in volts per centimetre and H is the electromagnetic field intensity measured in Gilberts per centimetre. In the following we will make use entirely of the electrostatic field, primarily because it bears a clearer relationship both to the position and type of the transmitting antenna and to the resultant effect on a receiving antenna.

BASIC FORM OF FIELD LINES.

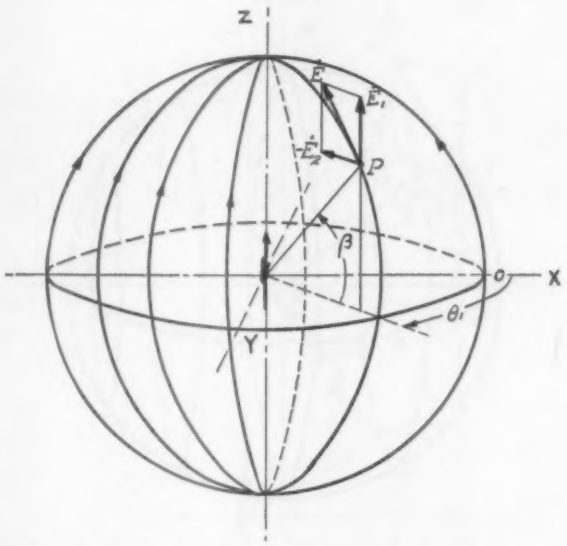
Before considering the actual intensity of the field at any point in space and at unit distance or, in other words, on the surface of an imaginary sphere whose radius is taken as unity, we will consider the direction of the electrostatic fields. In the case of a straight dipole antenna we know that the electrostatic field lines run from one end of the antenna to the opposite end and that these fields when radiated will obviously form great circles on our unit sphere whose common axes correspond with the antenna itself, as shown in Fig. 1. The field, being tangental to the vertical great circles, will be vertical only in the horizontal plane to which the antenna is itself perpendicular. In the case of the loop, the space phase displacement must be considered, from this, however, and from the assumed symmetry of the loop construction, it is at once obvious that the field along the surface of

the unit sphere forms along parallel circles, all of which are of course also parallel to the plane of the loop itself, as in Fig. 2.

POSITION AND INTENSITY OF FIELD.

(1) *The Simple Dipole Antenna.*—The intensity of effective electrostatic field at a point on the ground produced by a vertical antenna with large end capacity is $\mathfrak{E} = 188\ hI/\lambda d$, where h the height, λ the wave-length, and d the distance are measured in centimetres and I the current is measured in amperes (see Bulletin 354, Bureau of Standards) this value is the effective value of

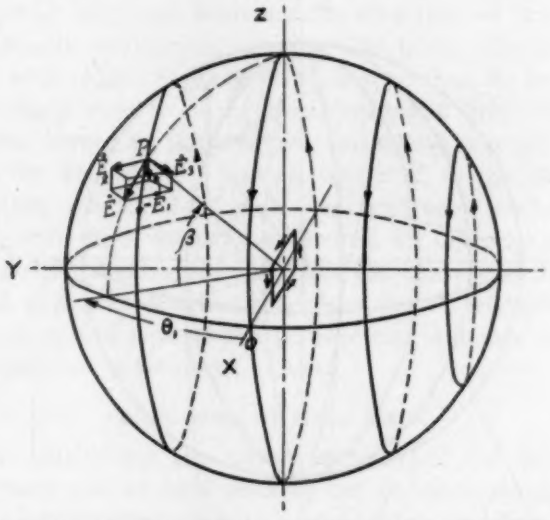
FIG. 1.



the field in the horizontal plane which in this case is a vertical field, as shown above, and which we will consider as of unit intensity at unit distance. The field intensity at any point on our imaginary sphere of unit radius will consequently be unity multiplied by a certain factor which we will call $\dot{E}$, so that $\dot{E}$ will itself represent the strength of the field at unit distance on any point of the sphere or $\dot{E}$ may be considered to express the intensity of the field at any point as its respective percentage value of the maximum field. The location of any point on our sphere can be determined by two angles, namely, the angle of elevation β measured upward from the horizontal plane and the angle of

departure θ, measured clockwise from the X axis as shown in Figs. 1, 2, 3, and 4. If a vertical antenna is to be considered, then the X axis may be arbitrarily chosen; if, on the other hand, a loop, inclined or horizontal antenna is concerned, then the X axis must correspond either with the intersection of the loop and the horizontal plane or with the projection of the antenna on the same. We know, as stated above, that the field must be tangental to the sphere at any point P; to investigate further we must, however, resolve the actual field into three components—$\dot{E}_1$, $\dot{E}_2$ and $\dot{E}_3$—which are obtained by projecting the field on the axes of a new

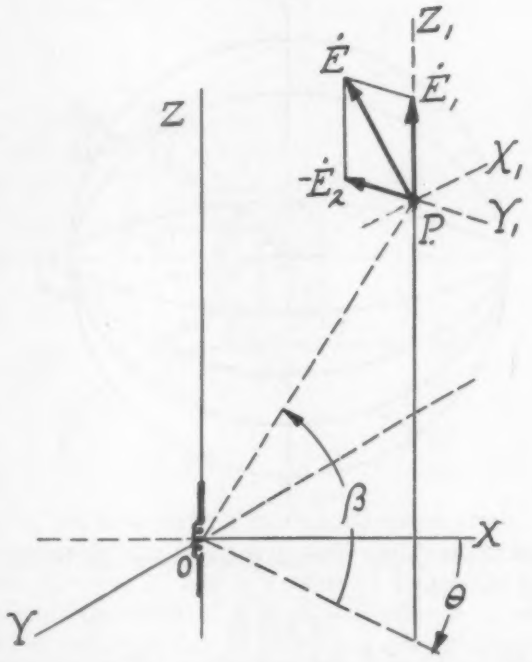
FIG. 2.



coördinate system whose centre is taken as P, the point under consideration. In the new system (Fig. 5) PZ' is the vertical axis, PY' the horizontal axis lying in the plane of propagation, and PX' the horizontal axis lying perpendicular to the plane of propagation. In order to obtain a basis of operation, it is necessary to choose positive and negative directions for these axes, by referring to Fig. 5 it will be seen that the PZ' axis is positive upward, the PX' axis is positive to the right when looking toward the source of radiation and the PY' axis is positive toward the reader or away from the source of radiation. The general procedure now to be followed in order to obtain expressions linking the field intensity with the position of the point P will be to con-

sider the field intensities of the total and component fields at various points on the sphere and to evolve therefrom general equations covering the same. If we will now regard the simplest case, namely, that of the *vertical dipole antenna*, we will find either through a consideration of the electrostatic field at the antenna or of the electron motion along the antenna (see "Principles of Radiotelegraphy" by Jansky, p. 74) that the field intensity is maximum at the horizontal plane and zero at the poles directly

FIG. 3.



above and below the antenna just as was the case with the light intensity from a straight filament, it can be shown further that this intensity follows the cosine law, so that the intensity of the field $\dot{E}$ can be at once expressed by the equation $\dot{E} = \cos \beta$. If we first, however, assume $\dot{E}$ to be constant at all points, we can state that the vertical projection of $\dot{E}$, that is the component $\dot{E}_1$, is zero when β is 90° and equal to $\dot{E}$ when β is 0°; in short, we can express $\dot{E}_1$ as equal to $\dot{E} \cos \beta$, as $\dot{E}$ is, however, not a con-

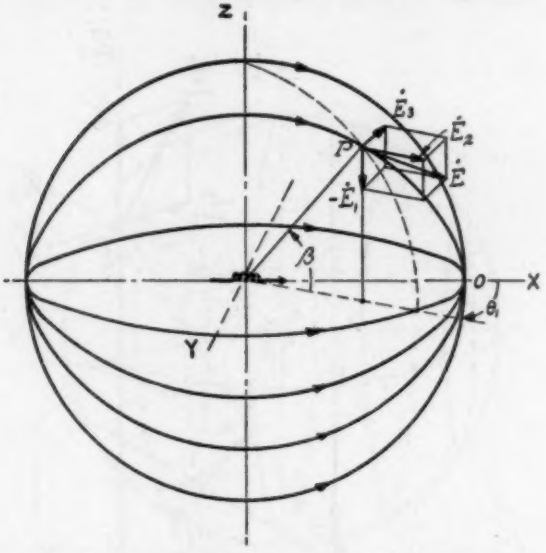
stant but a definite function of β, namely, cos β, we can at once write

$$\dot{E}_1 = \cos^2 \beta . \tag{1}$$

Similarly a horizontal projection of $\dot{E}$ on the horizontal plane or in this case on the PY' axis (Figs. 1 and 3) will be seen to be $\dot{E}_2 = -\dot{E} \sin \beta$, so that the actual value of

$$\dot{E}_2 = -\sin \beta \cos \beta . \tag{2}$$

FIG. 4.



As the field $\dot{E}$ lies in the vertical plane there can be no third component and the field

$$\dot{E}_3 = 0 . \tag{3}$$

To conclude, we have $\dot{E}$ the vector sum of its component fields, which is

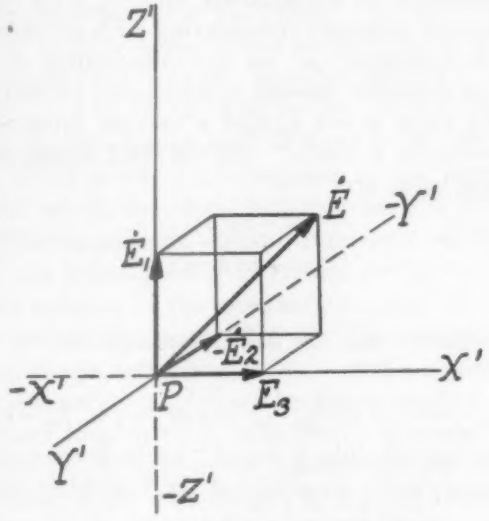
$$\cos \beta \sqrt{\cos^2 \beta + \sin^2 \beta} = \cos \beta , \tag{4}$$

as originally stated.

The next case to be considered is that of a *horizontal dipole antenna* and here on referring to Fig. 4 it will be immediately apparent that the second horizontal field $\dot{E}_3$ will not always be zero. We will first consider the fields under certain special conditions, first the condition under which $\dot{E}_3$ is zero and then the

condition under which $\dot{E}_1$ and $\dot{E}_2$ are zero. The first condition is met with when the angle θ_1 is zero, as we then have to do with the vertical great circle. Here $\dot{E}$ is therefore equal to $-\dot{E}\cos\beta$ by similar reasoning as before, and $\dot{E}_2$ is $\dot{E}\sin\beta$; however, $\dot{E}$ is now greatest when β is 90° and zero when β is zero, so that for this special case $\dot{E}=\sin\beta$ and, therefore, $\dot{E}_1=-\cos\beta\sin\beta$ and $\dot{E}_2=\sin^2\beta$, while $\dot{E}_3=0$, as by our basic assumption. The second special case, that is, when both $\dot{E}_2$ and $\dot{E}_1$ are zero, is met when

FIG. 5.



beta is zero as we now have a horizontal great circle. In this circle $\dot{E}_3$ is zero as before when θ_1 is zero and maximum when θ_1 is 90°, so that $\dot{E}_3=\sin\theta_1$, and this value of $\dot{E}_3$ will be seen to be true regardless of the value of β as $\dot{E}_3=\dot{E}$ when θ_1 is 90° at any elevation and is zero when θ_1 is zero as in the first special case. $\dot{E}_1$ and $\dot{E}_2$, on the other hand, are not only functions of beta, but are also proportional to θ_1, as they are zero when θ_1 is 90° and greatest when θ_1 is zero, they are therefore functions of or proportional to $\cos\theta_1$. Combining the various values of field intensities for the two special conditions, we can now write our general equations as follows:

$$\dot{E}_1=-\cos\beta\sin\beta\cos\theta_1\,; \tag{5}$$

$$\dot{E}_2=\sin^2\beta\cos\theta_1\,; \tag{6}$$

$$\dot{E}_3=\sin\theta_1\,, \tag{7}$$

while the vector sum of the component fields is

$$\dot{E} = \sqrt{\sin^2\beta\cos^2\beta + \sin^2\theta_1}, \tag{8}$$

which formula can be converted into

$$\dot{E} = \cos\theta_1\sqrt{\sin^2\beta + \tan^2\theta_1}. \tag{8}$$

From these two general formulæ, groups for the special cases of vertical and horizontal antennæ, we can now evolve the general formulæ for *inclined antennæ* of which the above are only special cases. To do this merely involves the addition of a new symbol, α_1, which represents the angle of the antenna with respect to the horizontal plane of reference; considering such an inclined antenna with a definite inclination α_1, we can immediately resolve it into two component antennæ, namely, a horizontal projection antenna whose relative value is $\cos\alpha_1$ and a vertical projection antenna whose relative value is $\sin\alpha_1$. As the field values of a vertical antenna of unit value are

$$\dot{E}_1 = \cos^2\beta, \tag{1}$$

$$\dot{E}_2 = -\sin\beta\cos\beta, \tag{2}$$

$$\dot{E}_3 = 0, \tag{3}$$

we see immediately that the field intensities due to the vertical projection antenna will be

$$\dot{E}_{v1} = \cos^2\beta\sin\alpha_1;\ \dot{E}_{v2} = -\sin\beta\cos\beta\sin\alpha_1;\ \dot{E}_{v3} = 0,$$

similarly, applying formulæ 5, 6 and 7 to the horizontal projection antenna of value $\cos\alpha_1$ we arrive at the following equations:

$$\dot{E}_{h1} = -\cos\beta\sin\beta\cos\theta_1\cos\alpha_1,$$

$$\dot{E}_{h2} = \sin^2\beta\cos\theta_1\cos\alpha_1,$$

$$\dot{E}_{h3} = \sin\theta_1\cos\alpha_1.$$

As these component fields are now known along the three axes of reference, it is only necessary to add the same algebraically in order to find the total field components along the three axes and to then finally obtain the vector sum of the three fields in order to find the total true field $\dot{E}$ due to an inclined antenna. $\dot{E}_1 = \dot{E}_{v1} + \dot{E}_{h1}$, etc., in this way we find

$$\dot{E}_1 = \cos^2\beta\sin\alpha_1 - \cos\beta\sin\beta\cos\theta_1\cos\alpha_1$$

which, after rearrangement and simplification becomes

$$\dot{E}_1 = \cos\beta\,(\sin\alpha_1\cos\beta - \cos\alpha_1\sin\beta\cos\theta_1); \tag{9}$$

similarly

$$\dot{E}_2 = \sin\beta\,(\cos\alpha_1 \sin\beta\cos\theta_1 - \sin\alpha_1\cos\beta) \tag{10}$$

and

$$\dot{E}_3 = \cos\alpha_1 \sin\theta_1 \tag{11}$$

and the total field or vector sum of the above is, after simplification,

$$\dot{E} = \sqrt{(\sin\alpha_1\cos\beta - \cos\alpha_1\sin\beta\cos\theta_1)^2 + \cos^2\alpha_1\sin^2\theta_1}\,. \tag{12}$$

It should be noted here that the formulæ for the inclined antenna are true only in space where a true inclined dipole can be obtained or where an inclined antenna operates against a small metallic counterpoise such as an airplane, on the ground the image effect is that of a second antenna half, inclined to the horizontal by the angle $-\alpha_1$ which is not a prolongation of the upper half of the antenna and which therefore balances out the horizontal component and leaves only the vertical component, so that an inclined antenna on the ground will give results similar to those obtained by a vertical antenna of the same height unless the whole antenna system is sufficiently removed from the ground and actually formed as a dipole antenna.

(2) *Polarization Angles.*—The above method of expressing the component intensities is sufficient to accurately describe the fields themselves. It is, however, interesting to consider the angles which the fields make with respect to a given coördinate system, such as the system $PX'Y'Z'$ previously described; in such a system it is necessary either to give the space angles between the field and the three coördinates, namely, ϕ between the field $\dot{E}$ and the X' axis, ψ between the field and the Y' axis, and ω between the field and the Z' axis, or the vertical angle from the Z' axis or ω and the horizontal angle π from the Y' axis to the horizontal projection of the field. In any case it will be seen, by referring to Fig. 6, that

$$\cos\phi = \dot{E}_3/\dot{E},\ \cos\psi = \dot{E}_2/\dot{E},\ \cos\omega = \dot{E}_1/\dot{E}$$

and

$$\tan\pi = \dot{E}_3/\dot{E}_2,$$

as an example, we will consider only the two special cases, namely,

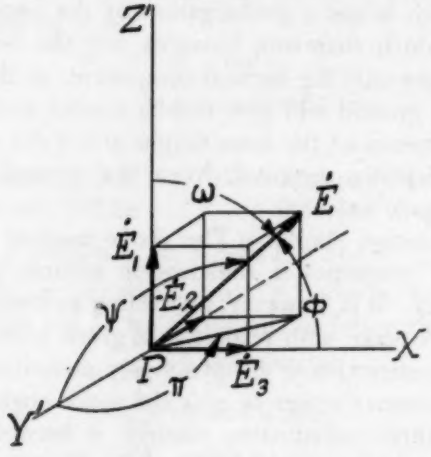
the vertical and the horizontal antenna, and for these we find the following results:

	Vertical Antenna.	Horizontal Antenna.
$\cos \phi =$	0	$\tan \theta_1 / \sqrt{\sin^2 \beta + \tan^2 \theta_1}$
$\cos \psi =$	$-\sin \beta$	$\sin^2 \beta / \sqrt{\sin^2 \beta + \tan^2 \theta_1}$
$\cos \omega =$	$\cos \beta$	$-\cos \beta \sin \beta / \sqrt{\sin^2 \beta + \tan^2 \theta_1}$
$\tan \pi =$	0	$\tan \theta_1 / \sin^2 \beta$

In the case of the vertical antenna, ω is seen to be equal to β and ψ to $90 + \beta$, while ϕ is seen to be 90° and π 180°.

(3) *The Loop as Antenna.*—To consider the loop, whose maximum field in the vertical plane is $\mathfrak{E} = 1185\ AL/\lambda^2 d$ (see p. 413, line 6) where A is the area in square centimetres, it will

FIG. 6.



be necessary to proceed in a manner similar to that followed in the previous case, for this reason we will first consider the *vertical loop*. As first special case we will consider the field components when θ_1 is zero (Fig. 2), that is, the field components in the plane of the loop. Considering the value of $\mathfrak{E}$ as unity at unit distance as before, we have $\dot{E} = 1$ along the great circle in question; while $\dot{E}_1$ the vertical component is 1 when β is 0° and 0 when β is 90°, E_1 is obviously a function of β and is actually expressed by cos β. Assuming P to be on the great circle and the instantaneous field to be downward, we see that E_1

is now negative. In a similar manner we find that the horizontal component $\dot{E}_2 = \sin \beta$, as it is 0 when β is 0° and 1 when β is 90°. The field $\dot{E}_3$ is obviously 0 in this special case. In the horizontal plane OXY, $\dot{E}_3$ is also zero as the field is here vertical, $\dot{E}_3$ is unity only when β is 90° and θ_1 is 90°, so that $\dot{E}_3 = \sin \beta \sin \theta$, similarly $\dot{E}_1$ and $\dot{E}_2$ become zero when θ_1 is 90°, so that both are proportional to $\cos \theta_1$ for the general case, we can therefore write

$$\dot{E}_1 = -\cos \beta \cos \theta_1, \tag{13}$$

$$\dot{E}_2 = \sin \beta \cos \theta_1, \tag{14}$$

$$\dot{E}_3 = \sin \beta \sin \theta_1, \tag{15}$$

the vector sum of these components is

$$\dot{E} = \sqrt{\cos^2 \theta_1 + \sin^2 \beta \sin^2 \theta_1} = \sqrt{\sin^2 \beta + \cos^2 \beta \cos^2 \theta_1} \tag{16}$$
$$= \sin \theta_1 \sqrt{\cot^2 \theta_1 + \sin^2 \beta} = \cos \beta \sqrt{\tan^2 \beta + \cos^2 \theta_1},$$

which formulæ are similar in form to those of the horizontal antenna, see equation 8. The polarization angles are here

$$\cos \psi = \tan \beta \cos \theta_1 / \sqrt{\tan^2 \beta + \cos^2 \theta_1}; \quad \cos \phi = \tan \beta \sin \theta_1 / \sqrt{\tan^2 \beta + \cos^2 \theta_1};$$

$$\cos \omega = -\cos \theta_1 / \sqrt{\tan^2 \beta + \cos^2 \theta_1}; \quad \tan \pi = \tan \theta_1.$$

π is seen to be equal to θ_1, which is apparent as the resultant field lies in a plane parallel to the plane of the loop. The second special case of a loop is the *horizontal loop*, and this is most simple as $\dot{E}_1$ and $\dot{E}_2$ are always zero (17 and 18), while

$$\dot{E}_3 = \cos \beta \tag{19}$$

and

$$\dot{E} = \cos \beta \tag{20}$$

as it is equal to $\dot{E}_3$. The polarization angles are $\phi = 0$, $\psi = 90°$, $\omega = 90°$ and $\pi = 90°$.

Having solved the two special cases, it is again a simple matter to solve the general case of the inclined loop by making use of the new term δ_1, which represents the angle between the plane of the loop and the horizontal plane, and by then considering the vertical projection loop whose value with respect to the inclined loop is

sin δ_1 and the horizontal projection loop whose value is cos δ_1. In this manner we obtain

$$\dot{E}_{v1} = -\cos\beta\cos\theta_1\sin\delta_1, \quad \dot{E}_{v2} = \sin\beta\cos\theta_1\sin\delta_1$$

and

$$\dot{E}_{v3} = \sin\beta\sin\theta_1\sin\delta_1,$$

from equations 13, 14, and 15, and

$$\dot{E}_{h1} = \dot{E}_{h2} = 0$$

and

$$\dot{E}_{h3} = \cos\beta\cos\delta_1$$

from equations 17, 18 and 19, and by addition we find the component fields to be

$$\dot{E}_1 = -\cos\beta\cos\theta_1\sin\delta_1, \tag{21}$$

$$\dot{E}_2 = \sin\beta\cos\theta_1\sin\delta_1, \tag{22}$$

$$\dot{E}_3 = \sin\beta\sin\theta_1\sin\delta_1 + \cos\beta\cos\delta_1, \tag{23}$$

while the vector sum of the component fields is

$$\dot{E} = \sqrt{\sin^2\delta_1(\cos^2\theta_1 + \sin^2\theta_1\sin^2\beta) + \cos\beta\cos\delta_1(\cos\beta\cos\delta_1 + 2\sin\beta\sin\theta_1\sin\delta_1)} \tag{24}$$

(4) *Antenna and Loop Combinations.*—It may be shown that if antennæ or loops and antennæ are combined, we can add the various component fields, respectively, if we know the relation of the maximum fields obtained from the antennæ or loops in question, for simplicity we will here assume that these intensities are of equal magnitude. As a first example let us consider a horizontal antenna and a vertical loop so dimensioned that their maximum fields at any point will be of equal intensity or in our case at unit distance they will be unity. By adding algebraically the equations 13, 14, and 15 for the loop to equations 5, 6, and 7 for the horizontal antenna, we obtain the fields

$$\dot{E}_1 = -\cos\beta\cos\theta_1(1+\sin\beta); \dot{E}_2 = \sin\beta\cos\theta_1(1+\sin\beta); \dot{E}_3 = \sin\theta_1(1+\sin\beta).$$

while the resultant field is found to be

$$\dot{E} = 1 + \sin\beta,$$

also

$$\phi = 90 - \theta_1, \quad \cos\psi = \sin\beta\cos\theta_1, \quad \cos\omega = -\cos\beta\cos\theta_1,$$

and

$$\tan \varepsilon = \tan \theta_1 / \sin \beta .$$

Similarly combining a vertical loop with a vertical antenna in order to obtain unidirectional effects, we must add equations 13, 14, and 15, respectively, to equations 1, 2, and 3, from which we obtain the equations

$$\dot{E}_1 = \cos \beta (\cos \beta - \cos \theta_1); \quad \dot{E}_2 = \sin \beta (\cos \theta_1 - \cos \beta); \quad \dot{E}_3 = \sin \beta \sin \theta_1 ,$$

while the resultant is

$$\dot{E} = \sqrt{1 - \cos \beta \cos \theta_1 (2 - \cos \beta \cos \theta_1)}$$

which simplifies to

$$\dot{E} = \cos \beta \cos \theta_1 - 1 .$$

When β is 0° this again simplifies to the well-known equation

$$\dot{E} = \cos \theta_1 - 1 .$$

The polarization angles for this case are found to be

$$\cos \phi = \sin \beta \sin \theta_1 / \cos \beta \cos \theta_1 - 1; \quad \cos \psi = \sin \beta (\cos \theta_1 - \cos \beta) / \cos \beta \cos \theta_1 - 1;$$
$$\cos \omega = \cos \beta (\cos \beta - \cos \theta_1) / \cos \beta \cos \theta_1 - 1$$

and

$$\varepsilon = -\beta .$$

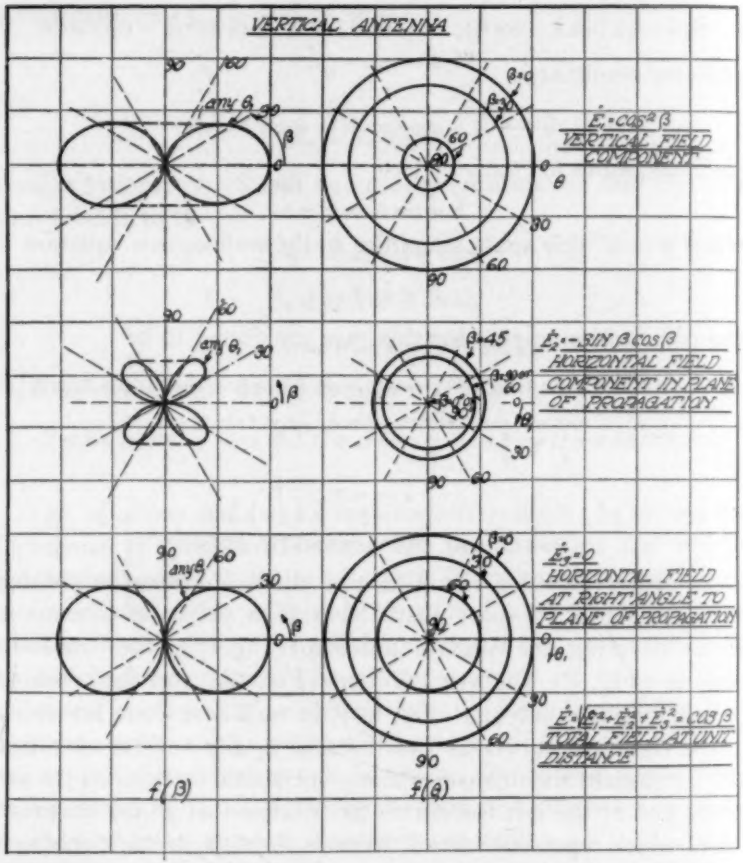
CHARTS AND CHARACTERISTIC CURVES.

In order to give a visual idea of the field strengths obtained at unit distance in space there have been prepared a series of curves covering the vertical antenna (Fig. 7), the horizontal antenna (Fig. 8), the vertical loop (Fig. 9), and the combined vertical loop and antenna (Fig. 10), in each case there are shown on the right the curves as functions of θ_1 for various elevations which represent the intensities along horizontal sections of the unit sphere and at the left the curves as functions of β for various θ_1 values which represent vertical sections through the unit sphere.

In conclusion it may be said that the component values of the fields are actually of more value to the observer or person interested in the signal or energy picked up by a receiving antenna than is the total field, this is at once obvious if we consider that the receiving antenna is vertical, for instance, as in the case of an antenna hanging from a free balloon, or horizontal, as might be

the case in a large airplane or airship. In the former case we would then be interested entirely in the field $\dot{E}_1$, while in the latter case we would be interested in the horizontal fields $\dot{E}_2$ and $\dot{E}_3$, this matter as well as the reception by inclined antennæ or loops will be discussed fully in a second paper, in which actual

FIG. 7.



measurements will be shown to correspond closely with calculated data. At present it will be sufficient to state that observations have been made in airplanes above vertical and inclined antennæ as well as above vertical and horizontal loops, which show that the assumptions and formulæ developed above are correct and account for all such phenomena as silent zones above vertical antennæ,

FIG. 8.

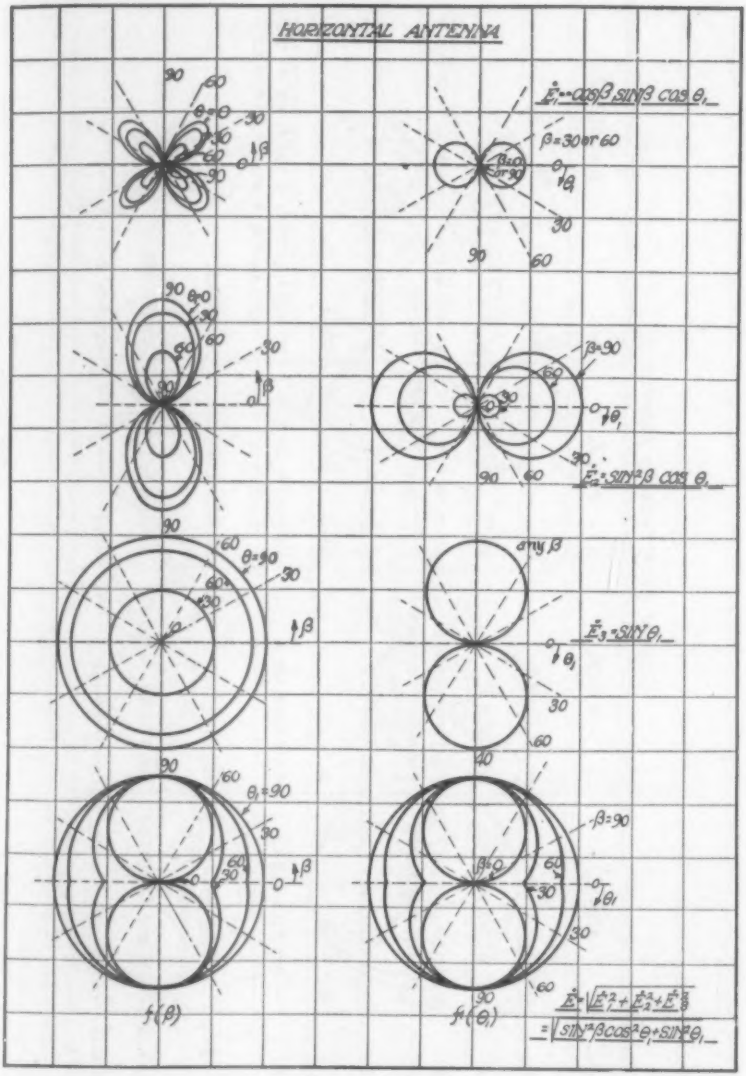

HORIZONTAL ANTENNA
$\dot{E}_1 = \cos\beta \sin\theta \cos\theta_1$
$\dot{E}_2 = \sin^2\beta \cos\theta_1$
$\dot{E}_3 = \sin\theta_1$
$\dot{E} = \sqrt{\dot{E}_1^2 + \dot{E}_2^2 + \dot{E}_3^2}$
$= \sqrt{\sin^2\beta\cos^2\theta_1 + \sin^2\theta_1}$
$f(\beta)$
$f(\theta_1)$

Chart of Field Intensity Equations.

Antenna.	Field $\bar{E}_1$.	Field $\bar{E}_2$.	Field $\bar{E}_3$.	Total Field $\bar{E}$.
V.A.	$\cos^2\beta$	$-\sin\beta\cos\beta$	0	$\cos\beta$
H.A.	$-\cos\beta\sin\beta\cos\theta_1$	$\sin^2\beta\cos\theta_1$	$\sin\theta_1$	$\sqrt{\sin^2\beta\cos^2\theta_1+\sin^2\theta_1}$
I.A.	$\cos\beta(\sin\alpha_1\cos\beta-\cos\alpha_1\sin\beta\cos\theta_1)$	$\sin\beta(\cos\alpha_1\sin\beta\cos\theta_1-\sin\alpha_1\cos\beta)$	$\cos\alpha_1\sin\theta_1$	$\sqrt{(\sin\alpha_1\cos\beta-\cos\alpha_1\sin\beta\cos\theta_1)^2+\cos^2\alpha_1\sin^2\theta_1}$
V.L.	$-\cos\beta\cos\theta_1$	$\sin\beta\cos\theta_1$	$\sin\beta\sin\theta_1$	$\sqrt{\cos^2\theta_1+\sin^2\theta_1\sin^2\beta}$
H.L.	0	0	$\cos\beta$	$\cos\beta$
I.L.	$-\cos\beta\cos\theta_1\sin\delta_1$	$\sin\beta\cos\theta_1\sin\delta_1$	$\sin\beta\sin\theta_1\sin\delta_1+\cos\beta\cos\delta_1$	$\sqrt{\sin^2\delta_1(\cos^2\theta_1+\sin^2\theta_1\sin^2\beta)+\cos\beta\cos\delta_1}$ $(\cos\beta\cos\delta_1+2\sin\beta\sin\theta_1\sin\delta_1)$
V.L. & H.A.	$-\cos\beta\cos\theta_1$ $(1+\sin\beta)$	$\sin\beta\cos\theta_1(1+\sin\beta)$	$\sin\theta_1(1+\sin\beta)$	$1+\sin\beta$
V.L. & V.A.	$\cos\beta(\cos\beta-\cos\theta_1)$	$\sin\beta(\cos\theta_1-\cos\beta)$	$\sin\beta\sin\theta_1$	$\cos\beta\cos\theta_1-1$
H.L. & V.A.	$\cos^2\beta$	$-\sin\beta\cos\beta$	$\cos\beta$	$\cos\beta\sqrt{2}$

FIG. 9.

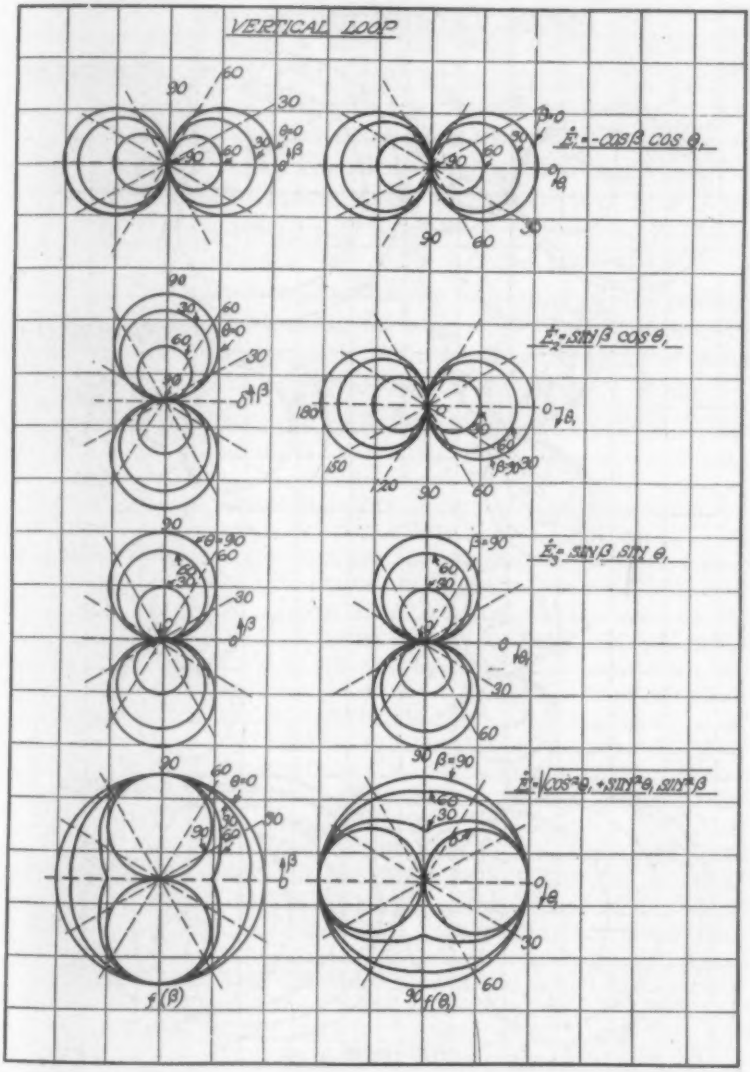
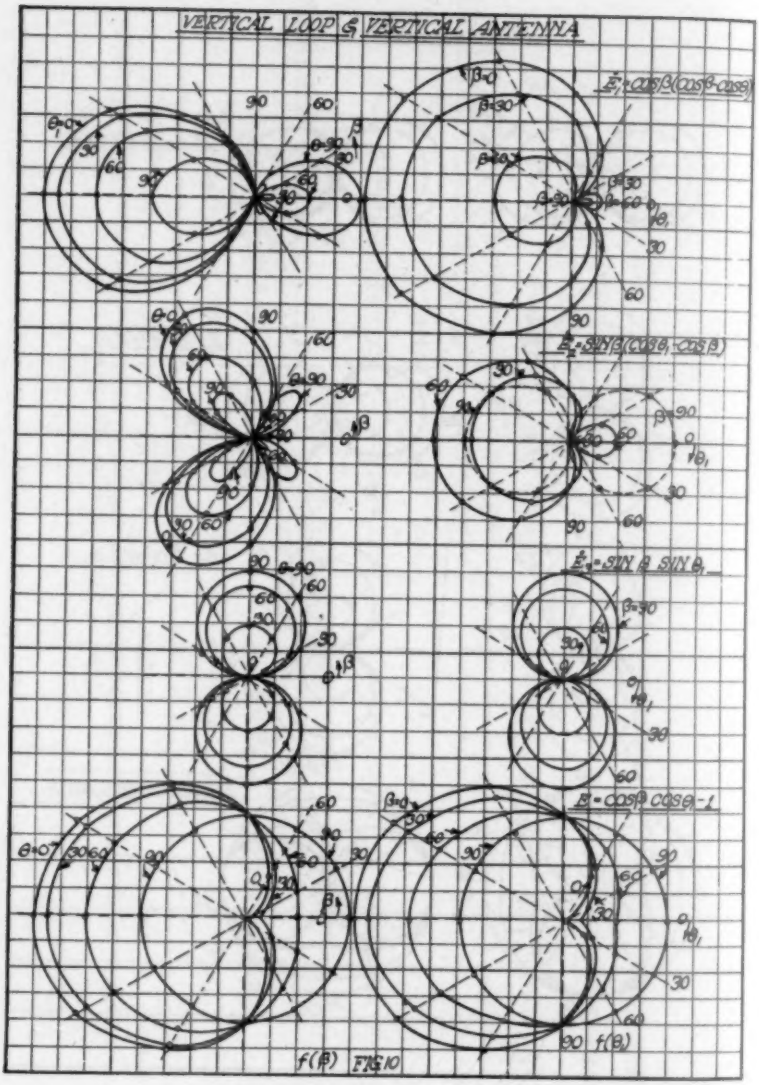

VERTICAL LOOP
$\dot{E}_1 = -\cos\beta \cos\theta_1$
$\dot{E}_2 = \sin\beta \cos\theta_1$
$\dot{E}_3 = \sin\beta \sin\theta_1$
$\dot{E} = \sqrt{\cos^2\theta_1 + \sin^2\theta_1 \sin^2\beta}$
f(β)
f(θ)

FIG. 10.



errors in bearings obtained in an airplane when receiving from a transmitting loop on the ground or *vice versa* and numerous other phenomena of a similar nature.

CONCLUDING RÉSUMÉ.

In the above paper a study has been made of the actual radiated fields in space at unit distance by resolving the true fields into three imaginary components, a vertical component, a horizontal component in the directional plane of wave propagation, and a horizontal component perpendicular to this plane of propagation. This has been done for special cases, such as for vertical and horizontal loops and antennæ and from these cases there have been evolved general formulæ for inclined loops and antennæ. In addition to this, the component fields due to loops and antennæ have been added and resultant formulæ derived therefrom. The method of expressing the angle of the fields with respect to certain axes of reference, in other words, the polarization of the field at any point in space has been discussed and formulæ derived for certain specific antennæ.

Apparatus for Demonstrating Thermal Transformations in Steel and Anomalies in Special Alloys. P. CHEVENARD. (*Jour. de Phys.*, Aug., 1925.)—To show recalescence two sets of metallic cylinders were formed with diameters roughly equal to two and one-half times the height. Holes were bored along the axis of each cylinder. One set was of ferro-nickel containing 25 per cent. nickel, the other of steel with .9 per cent. carbon. The cylinders were stacked upon a supporting pin so that the two metals alternated. The composite cylinder was heated to 900° C. and allowed to cool in the dark. The ferro-nickel undergoes no allotropic modification while the steel, on the contrary, does at its critical point. Thus as the stack of discs cools down, its brightness remains the same along its entire length until the critical point is reached. Thence the ferro-nickel continues to cool further and grows duller. The steel, on the other hand, shows the phenomenon of recalescence and grows brighter. The stack, previously of uniform brightness, then displays alternate bright and dark cylinders. The effect is accentuated by the contrast.

An ingenious apparatus is described whereby a spot of light moves along a curve, the ordinates of which are the thermal elongations of a wire of alloy and the abscissas the elongations of a wire free from thermal anomalies. Thus an audience may see the effects on the alloy of rapidity of cooling, of maximum temperature of heating and of the addition of various elements to its composition. The viscosity of metals at high temperatures can likewise be shown.

In the case of certain ferro-nickels the modulus of elasticity increases with temperature up to the Curie point. A flat spring, one, that is, with its parts all in one plane and not on a spiral, hangs with its length vertical and supports a weight at its lower end. An electric current traverses the spring, flowing through a contact made below the weight with a flexible blade. As the temperature of the spring is elevated by the current, its modulus increases and the weight is no longer able to stretch the spring as much as before. The spring therefore shortens, the contact is broken, the spring cools, the weight pulls it out to its former length, contact is reëstablished and the cycle repeats itself. Had the spring been in the form of a helix as in Roget's spiral the effect would be complicated by the attraction of the adjacent turns of wire.

A simple galvanometer is described. A vertical wire is made up of two parts that have about the same resistance. Both wires are of ferro-nickel, but one is of a kind whose modulus increases with rising temperature while that of the second kind falls. Where the two wires come together there is a pointer or a mirror attached. The two wires are twisted a little in opposite directions so that their torsional forces oppose each other. When an electric current passes, one wire becomes stiffer and the other less stiff owing to the rise of temperature. The stiffer wire then for a double reason gains upon the other and the pointer moves. Guillaume, whose kindness to American soldiers is gratefully remembered in Philadelphia, set out to compound a ferro-nickel of constant modulus of elasticity so far as temperature is concerned. So well is the effect of various elements on the properties of alloys known that he succeeded almost without any trials. The name "elinvar" has been bestowed on the ferro-nickel with constant modulus.

Some scientific results are attained by blows of the battle-ax. The present paper calls rather to mind the keenest rapiers.

G. F. S.

Permax, a Ferro-nickel with Remarkable Magnetic Properties. M. H. TSCHERNING. (*Jour. de Phys.*, Sept., 1925.)—The hysteresis curve for a magnetizing force of 200 gauss encloses scarcely any area at all, so closely together do the ascending and descending parts of the curve lie. The coercive force amounts to only .48 gauss. In contrast to this is the corresponding curve obtained with the magnetizing force equal to 10 gauss. The included area is considerable and the coercive force is noticeably greater than for the former cycle with larger magnetizing force. "One can say that for strong fields the hysteresis is extremely weak while for weak fields it is enormous in comparison to other kinds of iron and steel." For strong fields its permeability is small though for a field of 1 gauss it is considerable. At places on the hysteresis curve strong magnetic viscosity appears. It may take a dozen seconds for the pointer of the fluxmeter to reach a permanent position. G. F. S.

LATEST AND FUTURE DEVELOPMENTS IN POWER GENERATION.*

BY

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Consulting Engineer.

THE amount of mechanical power used by a nation is a surprisingly accurate index of its general prosperity. This was not always true and may not be true in some centuries to come, but it is undoubtedly true to-day and will be true for a great many years. It is not the purpose of this paper to go into the reasons for this or to show how much of the progress and civilization of a nation is due to the use of mechanical power. In the United States we have had an increase of power production of nearly 1500 per cent. during the last fifty years. At the present time the power consumption per man in England is about half of that in the United States and so is the purchasing power of the average man. In Japan the power consumption per man is about one-fourth of what it is here and so are the wages. The correlation is inevitable.

Let us, however, look into the problem of power production from an engineering point of view and see what has been accomplished, understand along what lines the latest developments in power generation are progressing, and along what lines our future endeavors should proceed.

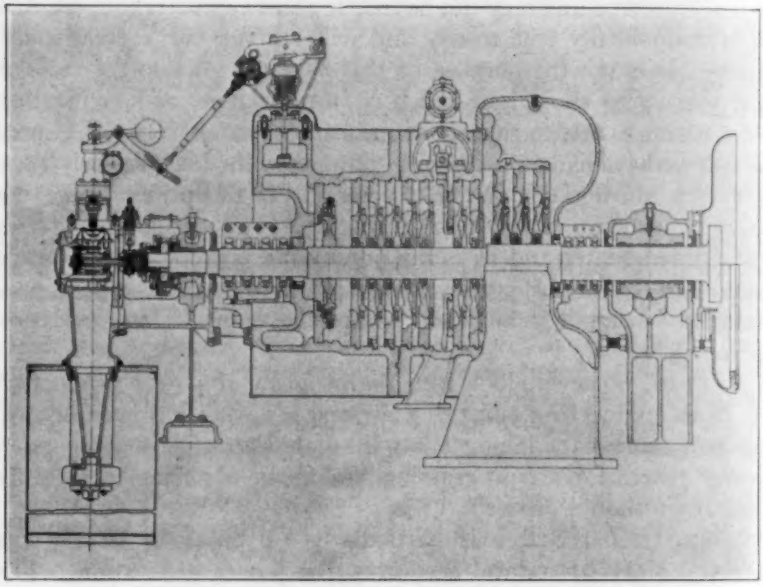
The United States is particularly fortunate in having the greatest store of natural resources for power generation. The largest source of power in this country, and in fact in the world, is coal. Second in importance is oil, and third, water-power. Means for utilizing wind-power have recently been improved and applied particularly to ship propulsion, but as yet no important power generation is obtainable from utilizing the wind. The same can be said of the attempts made at utilizing the terrestrial heat existing below the outer crust of the earth. This has been tapped of late and applied in a small way to industrial purposes. Neither wind-power nor terrestrial heat nor solar motors nor installations utilizing the rise or fall of water by tides are of any consequence in the general power situation. We have also large

* Presented at a meeting held Thursday, February 4, 1926.

quantities of natural gas in this country, and this gas is used for lighting, heating, and even power purposes. But no new sources of supply have been discovered and the present sources are steadily diminishing.

The United States produces one-half of the world's total supply of coal and over two-thirds of the world's supply of oil; and although the known available supply of coal is still plentiful,

FIG. 1.



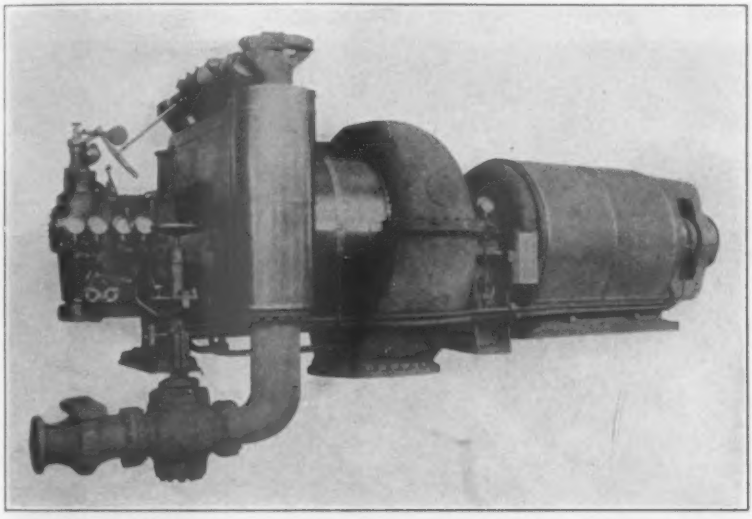
Assembly R-12-36 N. C. General Electric steam turbine.

we must consider seriously the problem of utilizing our natural resources in a far more economical way. In the case of oil, we produce and import over 800,000,000 barrels annually, of which 500,000,000 barrels are demanded to supply fuel to our 20,000,000 automobiles, 60,000,000 barrels are needed for oil-burning ships, 50,000,000 barrels are used by our railroads, 130,000,000 barrels are needed in our various industries, and about 60,000,000 barrels are consumed annually by our central stations producing gas and electricity. The present annual rate of consumption of oil is about one-twelfth of the known available oil supply in the world. This rate of consumption is increasing; and even considering that there

will be newly discovered oil fields, we must face the fact that the world's oil supply may be consumed within the next decade.

The situation with our coal supply is, however, much more favorable. We have available an estimated world's coal supply of about 8,000,000 millions of tons, of which the United States contains one-half. Our annual coal consumption is now about 650,000,000 tons, but this rate is increasing very rapidly. In

FIG. 2.



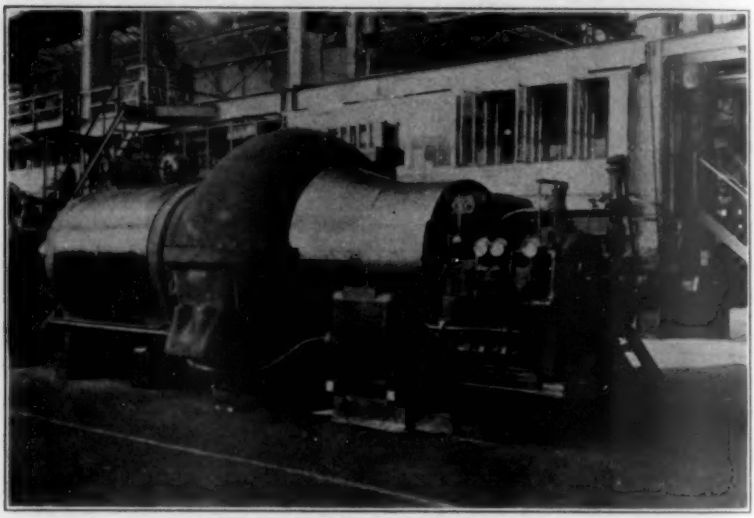
1500-kw., non-condensing type "R"-10-36, 3600-r.p.m. General Electric turbine generator set.

other words, our coal supply should last for a long time, but the price of coal will probably be higher from year to year.

Much progress has been made in the last few years in the development of oil engines, especially of the Diesel engine, both for stationary and marine purposes. The drawback of the Diesel engine is the limited output that can be obtained per engine cylinder. On account of the great heat developed during the burning of the oil in the cylinder, it is quite an engineering task to design the cylinders, valves, and pistons so as to secure the necessary strength and durability. Engines have been built with an output of 1000 h.p. per cylinder when single acting and about 2000 h.p. per cylinder when double acting. An engine of this type with six cylinders would be an enormous unit weighing many tons, and is probably as large as will be built in the near future.

The utilization of water-power has made great strides in this country during the last few years. Hydraulic turbines with efficiencies of 92 per cent. for turbine and generator have recently been built, and there is no doubt that in the future an increasing amount of power will be developed by hydraulic turbines. Last year's development in this country and Canada has totaled over 2,500,000 h.p. Some very large installations are either completed or nearing completion. Among these are 400,000 h.p. for the

FIG. 3.



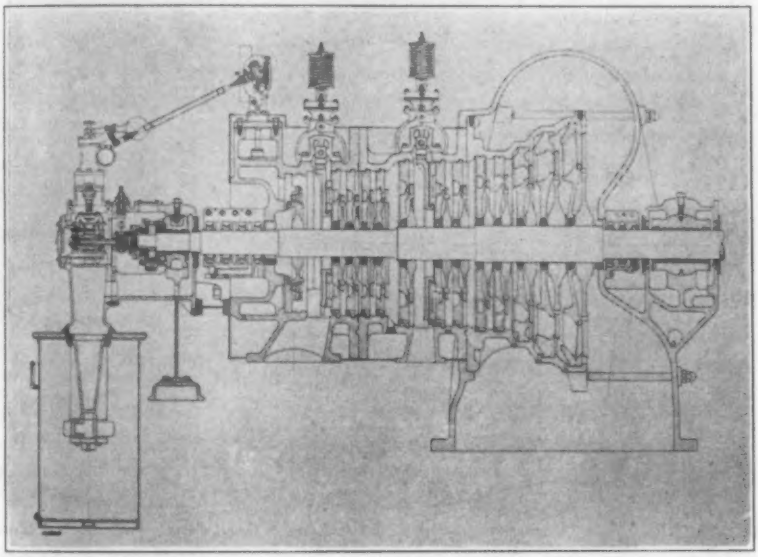
3000-kw. General Electric steam turbine set.

Quebec Development Company on the Saguenay River, and 260,000 h.p. for the Muscle Shoals Plant. The power generated at these plants, however, is available only over a limited area. The transmission of power over large areas is at present less economical than producing the necessary power in local power stations burning coal. The cost and losses of transmitting electrical energy prohibit the transmission of power over great distances. In one case, for instance, power could be generated in a coal-burning station just as cheaply as to bring hydro-electric power 150 miles over transmission lines.

As coal will be the greatest source of energy in this country for a long time to come, we shall devote most of our attention to power generation from coal. The bulk of electricity in this coun-

try is generated in central power stations. The total annual energy output of the central stations in the United States is now about 60,000 million kw.-hr., of which about one-half is used for driving machinery through electric motors, about one-fourth for lighting purposes, and one-eighth for electric railways, and the remaining one-eighth is either used in the generating stations themselves or is lost in transmission. The annual gross revenue of these stations is about $1,500,000,000. From this it can be seen that

FIG. 4.



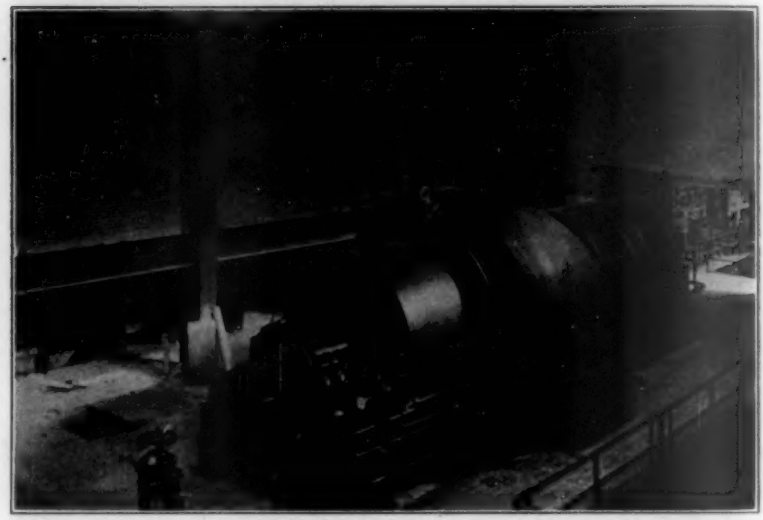
Assembly type R-12-60 double automatic extraction General Electric steam turbine.

the production of power is one of the leading industries in this country. The most economical way for producing electricity is in a large central power station. The larger the power station, the more economically is the power generated. We might at first suppose that the most logical place for a power station would be at the coal mines; but, as we shall see later, large power stations require large quantities of water. One of the large power stations in New York uses more water than is required for the entire water supply of that city. A large power station in Chicago uses the entire water flowing from the lake into the Chicago drainage canal. From this it is seen that the large central power

stations must be placed where there is abundant water and that the coal must be brought to them from the mines.

During the last few years some very important improvements in fuel economy have been made in this country. In 1913 the best designed central power stations delivered a kilowatt-hour with a fuel consumption of 22,500 B.t.u. Some of the stations constructed in the succeeding three years were able to reduce this value to as low as 20,000 B.t.u. per kilowatt-hour. We then

FIG. 5.



20,000-kw. General Electric turbine generator. Dallas Power and Light Company, Dallas, Texas.

reached a quiescent period of seven years, during which time no new development or manufacture was undertaken on account of the disruption caused by the war. But in 1923 we began to install a large number of new power stations in which some very important new developments were incorporated. We have just recently reached a remarkable figure in fuel consumption. A central station is now operating on a heat rate of 13,700 B.t.u. per kilowatt-hour.

Of course, reducing the number of B.t.u. per kilowatt-hour, that is, reducing the cost of fuel per kilowatt-hour, reduces only one of the items entering into the cost of producing electrical energy in our large power stations, the other three important items

being: Labor, maintenance, and fixed charges. In 1913, the total cost of producing a kilowatt-hour of output in a large central station was about 5 mills, of which 2 mills represented the cost of fuel, 2 mills covered the fixed charges, ½ mill went to labor and ½ mill was used for maintenance. Since 1913 the cost of labor has increased, but the cost of maintenance was reduced sufficiently to offset the higher cost of labor. This was chiefly due to the fact that larger units were installed which required less

FIG. 6.

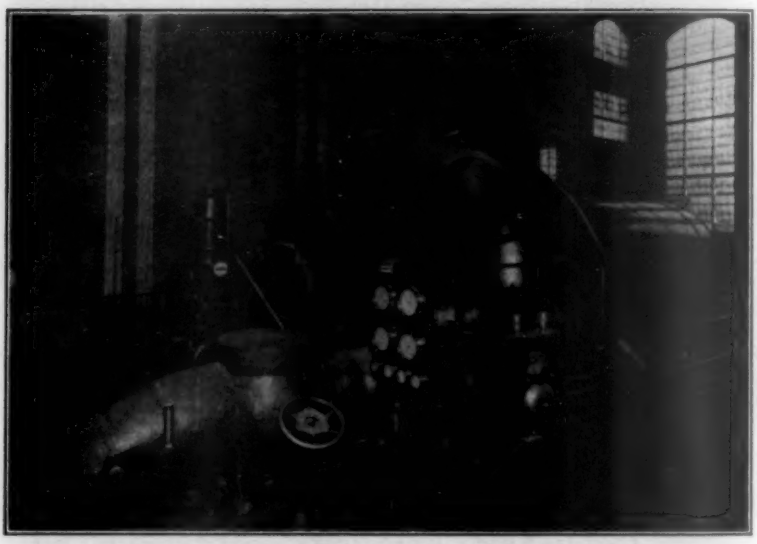
30,000-kw. turbine sets. Chester power house of Philadelphia Electric Company. General Electric steam turbine driving a B 4-33333, 1800-r.p.m., 14,000-volt General Electric generator.

attendance and maintenance charge per kilowatt-hour of output. Fixed charges since 1913 have doubled, and so has the cost of fuel. In 1923, the cost of fuel was 4¼ mills per kilowatt-hour of output, the fixed charges were about 4¼ mills, labor and maintenance demanded 1 mill, so that the total station cost per kilowatt-hour output that year was about 9½ mills. From 1923 until the end of 1925, due entirely to the wonderful engineering achievements in reducing the fuel consumption by over one-third, we have brought down the cost of electrical energy to about 8 mills per kilowatt-hour. As we shall see later, a much further

reduction in fuel consumption will hardly occur during the next five years, and it seems as if the largest gain in the immediate future will be made by a reduction of the fixed charges.

In order to understand thoroughly how this remarkable economy in fuel was brought about, we must keep before use the theoretical ideal to which engineering endeavor was and is striving. To utilize the heat value of the coal it is necessary to transfer this heat to a working medium. This working medium is water,

FIG. 7.

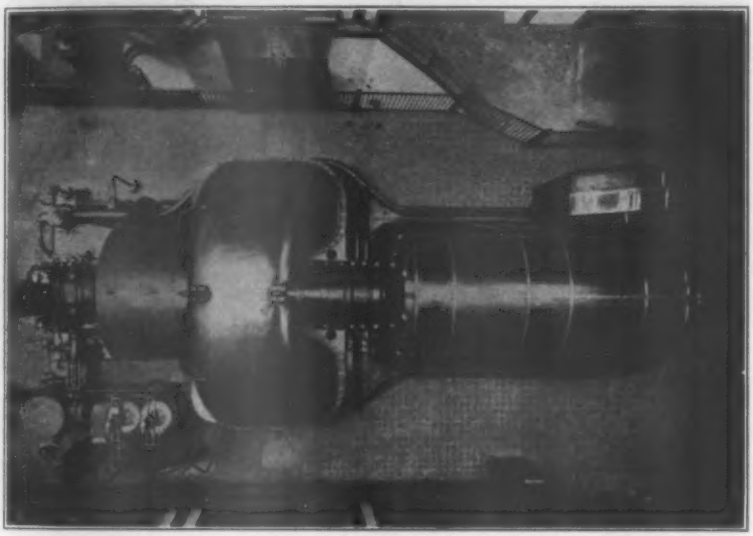


30,000-kw. General Electric steam turbine generator. Union Electric Light and Power Company, Cohokia Station, St. Louis, Mo.

which is universally attainable. Thermodynamics teaches that it is impossible to utilize heat energy without the presence of a difference of temperature levels. The work obtained from the falling of a weight is proportioned to the height through which it falls, and, in like manner, the work obtained from a given quantity of heat is proportioned to the range of temperature levels through which the working medium passes. Thermodynamics also teaches that the ideal cycle through which a working medium should pass in order to develop the most work from a given quantity of heat is one in which all the heat is added to the working medium at the highest possible temperature and all the

heat is abstracted from the working medium at the lowest possible temperature. This ideal cycle is the well-known Carnot cycle. It consists of compressing the working medium adiabatically, that is, without adding or subtracting heat, to the highest pressure obtainable; then adding heat isothermally, that is, at constant temperature; then allowing the working medium to expand adiabatically to the lowest obtainable pressure; and, finally, abstracting the heat from the working medium isothermally until the working

FIG. 8.



30,000-kw. General Electric steam turbine generator. Union Electric Light and Power Company, St. Louis, Mo.

medium has been brought back to its original condition and is ready to go through a similar cycle of operation.

In an actual power plant the working medium deviates from the ideal cycle in a number of ways. Beginning with the water at its lowest temperature and pressure, it is forced by a pump against boiler pressure through a preheater where its temperature is raised to almost the boiling-point corresponding to the boiler pressure. Heat in this operation is therefore supplied at a gradually increasing temperature, and therefore not isothermally and not at the highest temperature of the cycle. Upon reaching the boiler, the water is evaporated into steam and this operation is carried through strictly isothermally. The steam then passes through

superheaters, where it is heated at constantly rising temperatures until it reaches the maximum temperature, hence here also heat is not being added isothermally. The steam is then led to the heat engine, almost invariably a steam turbine, where it expands nearly adiabatically to its lowest temperature and pressure. Heat is then subtracted from the working medium by the condenser,

FIG. 9.

Two 30,000-kw. General Electric steam turbine generators with 2000-kw. service generators. The Edison Electric Illuminating Company, Weymouth Station, Boston, Mass.

usually isothermally, and reaches finally its initial state at the beginning of the cycle.

Let us now take up the principal factors which during the last few years contributed in securing the fuel economy mentioned before. The boiler plant has experienced a very remarkable evolution, and more has been accomplished in the last three years in increasing the efficiency of the boiler plant than was ever accomplished in any previous decade.

Coal is now no longer hand-fired, mechanical stokers guaranteeing more uniform firing, which means more uniform combustion and generation of steam. But the real advance during the last two years has been in the methods of pulverizing the coal and in controlling the air required for burning the coal.

Special attention has lately been given to the question of preheating the air for combustion, and recent results have proven that the expectations in this direction were fully realized. This air is being preheated by the waste products of combustion as they enter the chimney and still contain enough heat for this purpose. The air for combustion is also made to pass around the

FIG. 10.

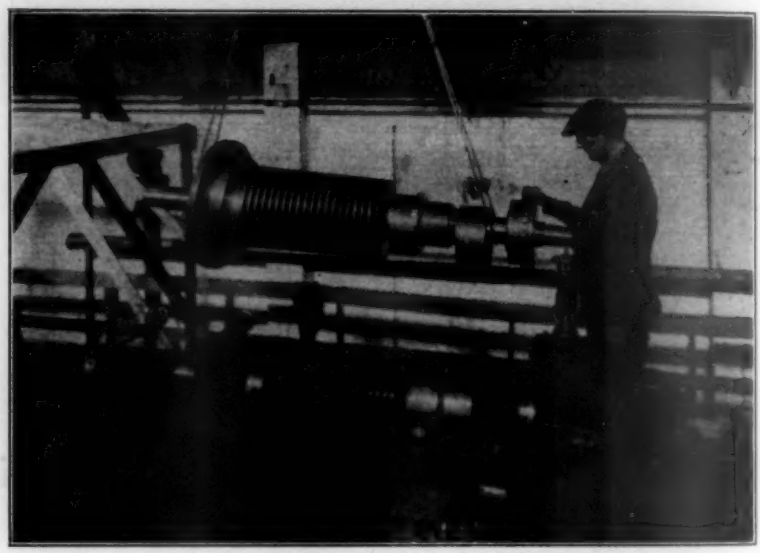
2400-kw., 3600-r.p.m., 20-stage turbine for Boston Edison Company operating at 1200-lb. steam pressure.

walls of the furnace. Preheating the air to 600° has been accomplished and it seems as if 800° will be practical in the future.

Probably the largest gain in boiler economy was due to the recent endeavors to utilize more fully the radiant heat of the flame. Experience now shows that it is extremely important to transfer as much as possible of the heat generated by the coal to the water by radiation as the rate of absorption by radiant heat is nearly ten times that by convection. Data have been obtained which indicate that the furnace radiation to a metal side wall may be as high as 75,000 B.t.u. per square foot per hour. Much work is now being done both theoretically and practically to ascertain the specific values of radiant heat absorption under varying conditions of heat release. It has been found that CO_2

and water vapor have the properties of both absorbing and of emitting radiant heat. I believe we will not be wrong in saying that in the near future boiler ratings will range from 1500 to 2000 per cent. and that the steam-making surfaces in boilers will be reduced from the present average of 1½ square feet per kilowatt of station capacity to probably ¼ square foot. The River Station Extension of the Buffalo General Electric Company has now under construction a boiler plant on the basis of ¾ square

FIG. 11.



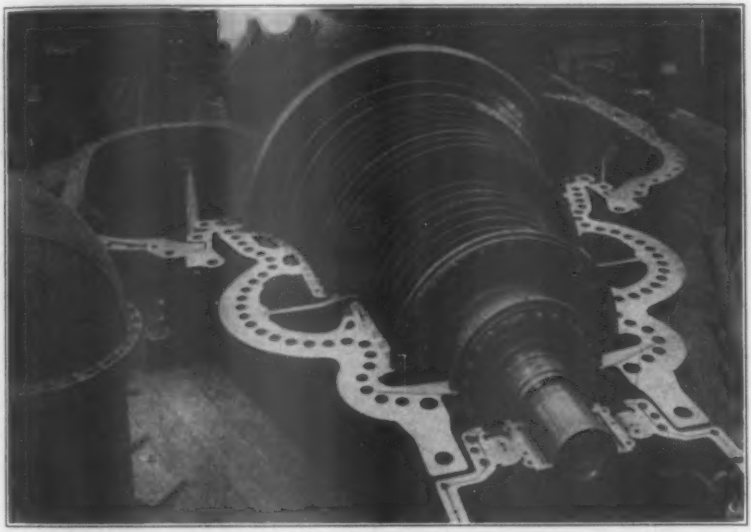
Rotor for 2400-kw., 3600-r.p.m., 20-stage turbine for Boston Edison Company.

foot of boiler heating surface per kilowatt of station capacity, and will use pulverized coal. Taking full advantage of utilizing the radiant heat of combustion will necessitate building the furnace walls so that they can be cooled by water, and furnaces with water-cooled walls have already been built. Obviously, it is extremely important to have the proper regulation of the air supply for combustion because a deficiency of air leaves unburned CO in the products of combustion and too much air causes a waste of heat. The proper firing of a boiler has really become a fine art.

A very vital problem has engaged and is engaging the attention of engineers and that is the question of raising the pressures

and temperatures of the steam available to the steam turbine. We all know that the Carnot cycle demands for high efficiency the raising of the maximum temperature of the cycle to as high a figure as possible. Our limitations lie in the materials available for boiler and turbine construction. Steel at 800° F. becomes luminous in a darkened room and decreases very quickly in strength when heated beyond this temperature. Only a few years ago a central station operating with 250 lb. steam and 500° F.

FIG. 12.

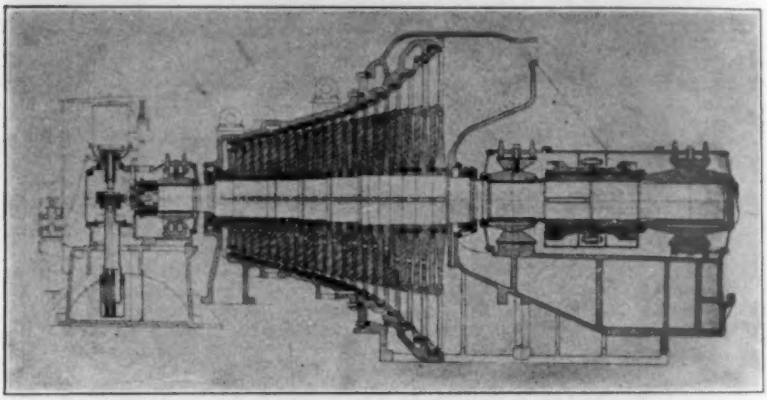


Lower half shell of 19-stage, 35,000-kw. turbine with wheels in place, showing arrangement for extracting steam from seventh stage to be reheated and led back to eighth stage.

temperature was considered good practice. To-day temperatures from 750 to 800° are being used. Some new material is badly needed that will retain its strength at high temperatures. Experiments recently made indicate that we shall soon have alloy steels which can be used with steam temperatures of 1000°. One American manufacturer is now offering valves and fittings suitable for this temperature, and in England they are discussing materials that may be used up to 1300°. Most of our new power stations are using pressures in the neighborhood of 400 lb. In this connection it is interesting to note the new installations at the Edgar Station of the Edison Electric Illuminating Company of Boston,

at Weymouth, Mass. The main part of this power station is operating at 375-lb. pressure. In order to increase the efficiency of the plant, there have been added a boiler and a turbine operating at 1200-lb. pressure. The turbine receiving the 1200-lb. steam exhausts it into the 375-lb. main steam line of the station. This 1200-lb. turbine will be illustrated later. The entire industry is closely watching the operation of this installation; the excellent gain in station economy is already known. It may be interesting to mention that in Czechoslovakia a contract has been entered into

FIG. 13.



50,000-kw., 1200-r.p.m., 21-stage General Electric steam turbine.

for a power station utilizing steam at 1700-lb. pressure and 925° temperature, and the turbine is to be an 1800-kw. unit. It is not altogether certain at the present time whether a plant operating at a pressure of 400 lb. and 825° would be more efficient than a 1200-lb., 700° plant. The tendency at present is in favor of the former. With 400-lb. pressure our metals can be subjected to steam of 825° to 850°, but with 1200-lb. pressure these metals should not be subjected to over 700°.

Another gain in both fuel economy and in maintenance and investment cost has been achieved by increasing the size of the turbo-generator unit. During the last year all three of the large turbine manufacturers in this country have built turbines of larger capacity than previously. Three years ago the largest turbo-generator in operation had a capacity of 30,000 kw. To-day we have units of 50,000 and 60,000 kw. in operation. A 77,000-kw.

unit is in order for the Crawford Avenue Station in Chicago, and an 80,000-kw. cross-compound turbo-generator will be installed this year at the Hudson Avenue Station of the Brooklyn Edison Company. A 150,000-kva. steam turbo-generator is being considered for a new power station in the Middle West. Steam turbine economies have now reached a point where further great advances cannot reasonably be expected, although some improvement may be obtained through the intensive study and persistent research regarding the behavior of steam in buckets and nozzles.

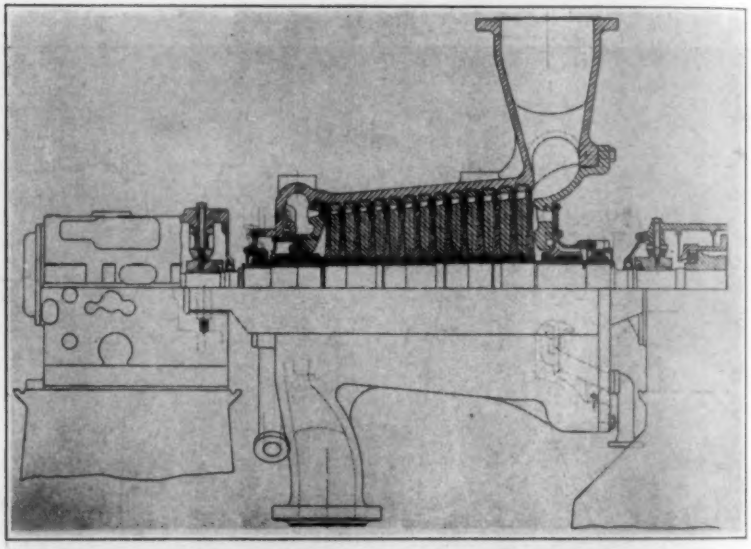
FIG. 14.

Three 50,000-kw., 62,500-kva., 1200-r.p.m., 60-cycle General Electric steam turbine generators, Trenton channel station, Detroit Edison Company, Detroit, Mich.

The greatest gain in efficiency is obtained by increasing the steam pressure and temperature, but important gains have also been obtained by reheating the steam between stages of the turbine after it has done a certain portion of its total work. This not only increases the efficiency of the steam turbine, but also the efficiency of the steam cycle. It removes moisture from the turbine, thereby considerably reducing bucket deterioration. In going to such high steam pressures as 1200 lb., the steam in expanding through the low-pressure stages of the turbine would carry considerable moisture, which, besides having a deteriorating effect on the turbine buckets, would increase the rotation losses of the rotating

wheels. In central stations that have used high steam pressures, reheating the steam has been resorted to. The method has been to install special secondary superheaters in the boiler setting with comparatively large pipes carrying the steam from and returning it to the turbine. This method, however, is somewhat complicated on account of the proportions that are necessary so as to guard against expansion and eventualities in case of a sudden reduction of load. Although this method is perhaps the most economical,

FIG. 15.



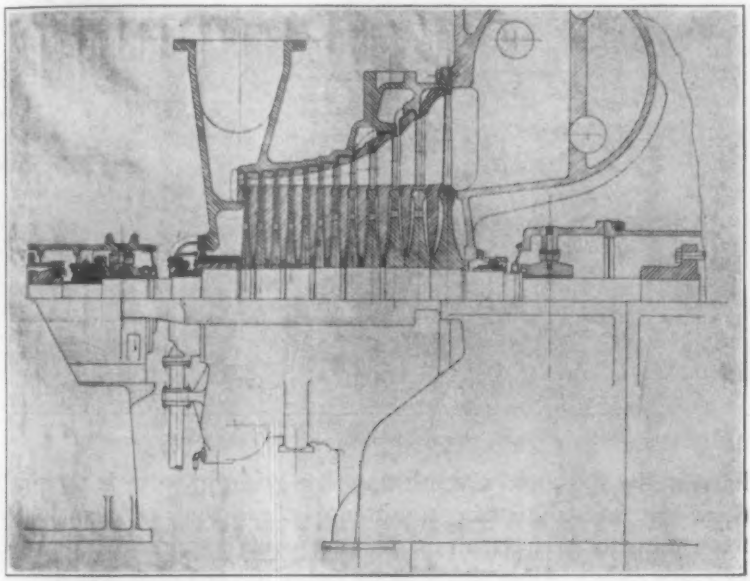
High-pressure section of 40,000-kw., 1800-r.p.m., 26-stage tandem compound turbine.

we may find in the future separately fired superheaters located in the turbine room; or we may find that the steam flowing through the turbine will be reheated by bringing live steam from the boiler to a reheater in the turbine room. In this case the obtainable reheat temperature is low, but the gain in thermal efficiency is large.

Another factor in improving station economy was introduced during the last few years and especially during the last year in the preheating of the feed-water to the boilers. Three years ago, the newly adopted method of preheating the feed-water by means of the exhaust steam from a house service turbine was considered the best practice. In large central power stations it was found

efficient to drive all the auxiliaries by electric motors. This includes the auxiliaries of the steam-condensing plant, the feed-water pumps, the operating motors of the mechanical stokers and coal pulverizers, ventilating fans, etc. For this purpose, a house service turbo-generator set was used; so that, if anything should happen to the main generating units, an independent source of power would be available for keeping the auxiliary machines running in the power stations. These house service turbines were

FIG. 16.



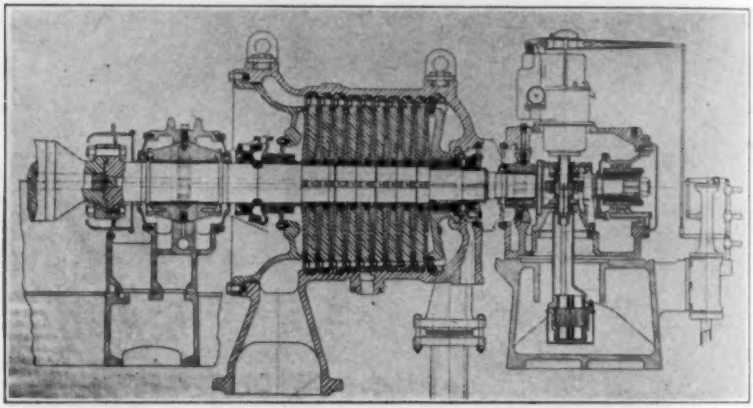
Low-pressure unit of 40,000-kw., 1800-r.p.m., 26-stage tandem compound turbine.

from 500 to 3000 kw. in size and were designed to operate so as to exhaust the steam from the turbine at various back pressures, since the higher the back pressure the hotter the steam available for preheating the feed-water. Automatic devices were used to change this back pressure so as to preheat the feed-water to a constant temperature. Recently, however, it was found more economical to bleed the main turbine at several points and use this bleeder scheme for preheating the feed-water. Theoretically, steam bleeding from a great many stages of the turbine increases the efficiency of the plant, but for practical reasons the number of bled stages has been limited to four, with the greater number of

plants using three. Over 95 per cent. of all the larger central power stations placed in operation since 1923 preheat the feed-water by this method. Over 50 per cent. use three-stage bleeding; about 25 per cent. use two-stage bleeding; and nearly 20 per cent. use four-stage bleeding. The feed-water is now preheated to practically the boiling temperature of the boiler.

Fig. 1 represents a non-condensing steam turbine arranged for steam extraction or for mixed pressure steam operation.

FIG. 17.



17,000-kw., 1800-r.p.m., 10-stage, high-pressure unit of 60,000-kw. turbine.

Between the sixth and seventh stages, a gridiron valve is provided which regulates the steam admitted to the seventh stage. If the steam pressure between the sixth and seventh stages becomes too high, due either to less steam being extracted at this point or more steam being admitted at this point, the gridiron valve opens and permits a larger steam flow through the low-pressure end of the turbine. If the stage pressure drops, the gridiron valve automatically closes.

Not so many years ago, a 1500-kw. turbo-generator set was considered a rather large unit. Fig. 2 is a photograph of such a unit and illustrates how small and compact they are now built.

Fig. 3 is a photograph of a 3000-kw. turbo-generator set operating at 3600 r.p.m.

Fig. 4 illustrates a turbine with double automatic extraction.

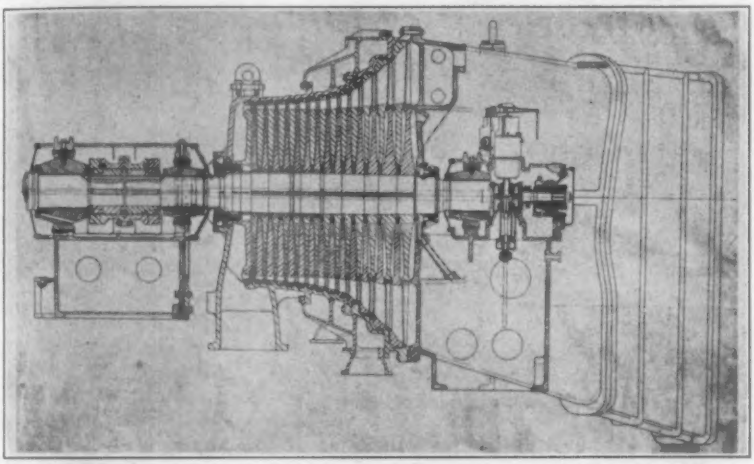
Fig. 5 is a photograph of a 20,000-kw. turbo-generator installed at the Dallas Power and Light Company's plant at Dallas,

Texas. These units are now used to a large extent in the moderate-sized power plants in this country.

A 30,000-kw. unit was considered a very large unit in 1923. Fig. 6 is a photograph of two of these units in the Chester power house of the Philadelphia Electric Company. These units run at 1800 r.p.m.

Fig. 7 is another photograph of a 30,000-kw. turbo-generator installed in the Cohokia Station of the Union Electric Light and

FIG. 18.



43,000-kw., 1200-r.p.m., 14-stage, low-pressure unit of 60,000-kw. turbine.

Power Company of St. Louis, and Fig. 8 is a photograph looking down on the top of this same unit.

Fig. 9 is a photograph of two 30,000-kw. turbo-generators installed at the Weymouth Station of the Edison Electric Illuminating Company of Boston, and also shows a 2000-kw. house service turbo-generator. It is in this station that the 1200-lb. high-pressure turbine was installed exhausting into the main steam line supplying these 30,000-kw. units.

Fig. 10 is a photograph of this 1200-lb. turbine. It delivers 2400 kw., runs at 3600 r.p.m., and contains twenty stages. From the photograph we can note the enormous thicknesses of the cast-steel casing to take care of these high pressures and temperatures.

In Fig. 11 the turbine rotor can be seen as it is being lowered into the lower half of the turbine casing. The turbine wheel

diameters are very small, because large diameters would mean large rotation losses; as these turbine wheels rotate in an atmosphere of high density steam. The rotation losses increase with the fifth power of the diameter of the turbine wheel, with the third power of the r.p.m., and directly with the density. Special care in the design of the packings preventing steam leakage along the shaft had to be observed.

In Fig. 12 is shown the lower half-shell of a 19-stage,

FIG. 19.

60,000-kw. turbine generator for Commonwealth Edison Company. Upper half of turbine casing for h.p. unit.

35,000-kw. turbine with the turbine rotor in place, and we can see clearly the arrangement for extracting steam from the seventh stage so that it can be reheated and led back again to the eighth stage.

Fig. 13 shows a 21-stage, 50,000-kw., 1200-r.p.m. turbine, and Fig. 14 shows three of these units installed at the Trenton Channel Station of the Detroit Edison Company.

A somewhat different design is shown in Figs. 15 and 16. Fig. 15 is the high-pressure end of a 40,000-kw., 1800-r.p.m., tandem compound turbine. It has fourteen stages in the high-pressure end and twelve stages in the low-pressure end, as shown in Fig. 16; that is, the turbine contains twenty-six stages in all.

A 60,000-kw. turbine is operating at the Commonwealth Edison Company's plant at Chicago, and consists of a high-pressure unit of 17,000-kw. capacity running at 1800 r.p.m. and has ten stages. The low-pressure unit gives an output of 43,000 kw., and runs at 1200 r.p.m. and has fourteen stages, as is shown in Figs. 17 and 18. To give an idea of the enormous size of these units, Fig. 19 shows the upper half of the turbine casing for the high-pressure unit, and Fig. 20 the lower half of the exhaust

FIG. 20.

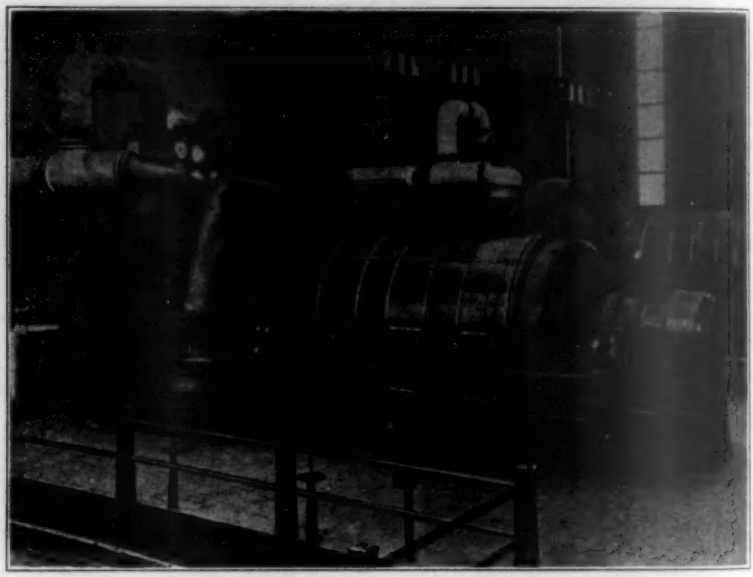
60,000-kw. turbine generator set for Commonwealth Edison Company. Lower half of exhaust hood for L. P. turbine.

hood of the low-pressure turbine. This 60,000-kw. unit was placed in operation about a year ago. The first 60,000-kw. unit operated about six months without any steam reheat until two other units of this size were installed. Since May, 1925, this unit has been operating with entire satisfaction with steam reheat and no adjustments of any kind are necessary in going from operation with reheat to operation without reheat.

A very interesting installation is that of the Philo Station of the Ohio Power Company. The turbo-generator units installed there are rated 40,000 kw. each. The first unit went into commercial operation towards the end of 1924. These units are oper-

ating under steam conditions of 600-lb. gauge and 725° total temperature. After the steam has passed partially through the turbine, the steam is reheated to its initial temperature. The turbines are also arranged for multi-stage extraction. The station operating records have shown monthly economies of 14,000 B.t.u. per kilowatt-hour, the output being measured at the high-tension outgoing lines so that this figure also includes the transformer losses. This station was and still is of interest to engineers as

FIG. 21.



View of 40,000-kw. turbo-generators at Philadelphia station.

having demonstrated that it is possible to produce a net kilowatt-hour for one pound of good coal. Fig. 21 is a photograph of the 40,000-kw. units in this station, and Fig. 22 gives a general view of the power station.

Although the advance made in securing good fuel economy has been most remarkable during the last few years, there seems to be little expectation that we can go very much further in fuel economy in the future unless something very radically new is proposed and tried out. The steam-generating plant has now reached the remarkable efficiency of 93 per cent., that is, 93 per cent. of the heat of the coal is transferred to the steam as it leaves

the boiler. The largest loss is the heat that is carried away in the waste gases as they pass up the chimney. Some of this heat might be utilized but it would require very large dimensions of flues, and the added cost would probably not be economical at the present time.

Turbines have been built and are now operating with over 80 per cent. efficiency, that is, the turbine is converting over 80 per cent. of what it can theoretically convert into mechanical work

FIG. 22.

General view of Philo power station of Ohio Power Company.

if it operated without any losses. The generator end has not experienced any such radical changes during the last few years as far as efficiency is concerned, chiefly because these generators have given efficiencies of 96 and 97 per cent., but a great deal of engineering skill was required to build the generators for the enormous outputs required by the larger turbines recently installed.

Referred to the Carnot cycle, large central stations are now approaching very nearly 30 per cent. thermal efficiencies, that is, 30 per cent. of the entire heat energy of the coal is delivered in electrical energy. Of the 70 per cent. heat losses about 50 per cent. is carried away by the cooling water of the condenser, and this is an unavoidable loss as long as we will operate with water

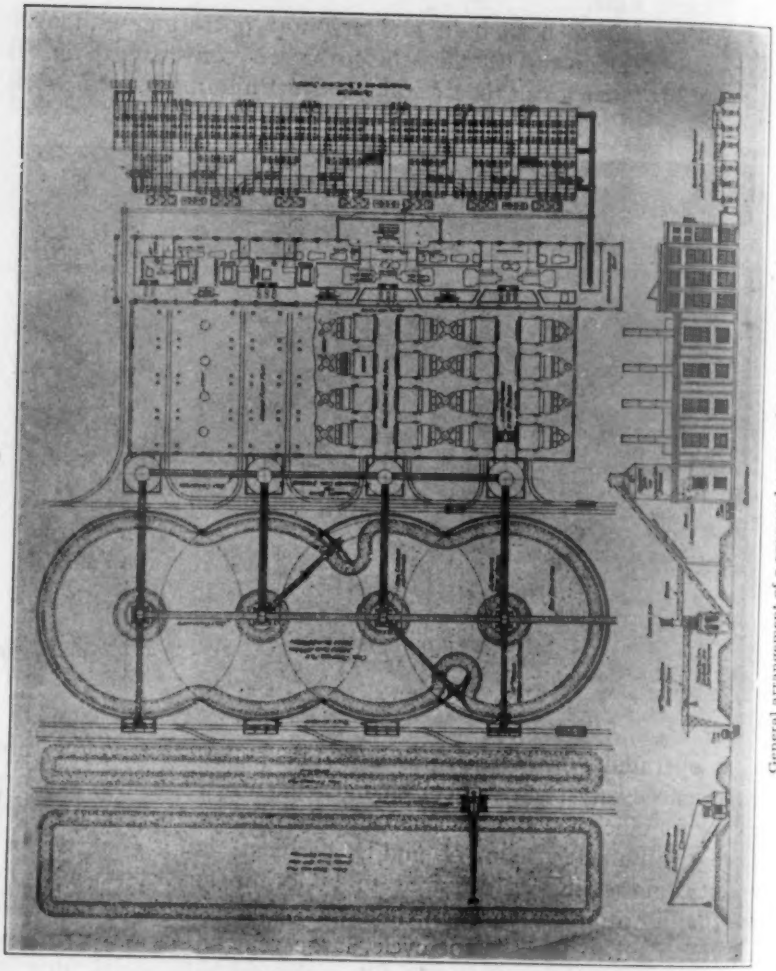


FIG. 23.

General arrangement of a proposed 245,000-kw. steam power plant.

as the working medium and with steam boilers, steam turbines, and generators.

Before we take up the question as to what we might expect during the next decade, it may be interesting to show a complete layout of an up-to-date large central power station containing the latest ideas in boilers, preheaters, economizers, feed-water heating, turbo-generators, reheating between stages, condensers, etc. The next four figures illustrate a proposed 245,000-kw. steam power station. Fig. 23 shows the general arrangement of such a station, and Fig. 24 gives a partial floor plan of this station to a larger scale. Fig. 25 is a sectional view of the boiler plant, and Fig. 26 shows sectional views of the station.

We now come to an important new development in which an attempt is made to carry out what has been theoretically suggested a great many years ago as a means by which the thermal efficiency of a power station might be increased. As we know, the thermal efficiency of a cycle is highest if the heat at our disposal can be added to the working medium at the highest temperature attainable. At the critical pressure of water about 3200 lb./sq. in., the boiling-point is a little above 700° F. This is the maximum temperature at which heat can be added to water isothermally. Suggestions were made to use other liquids which have a higher boiling-point, and to use these liquids for the upper temperature range of the cycle and to condense them at a sufficiently low temperature so that another liquid, as water, for instance, could be vaporized at constant temperature. In other words, the heat cycle is to be carried out by a binary-vapor process. Certain hydrocarbons derived from benzol were suggested, and some of these substances were tried; but although they boiled at high temperatures, they decomposed and degenerated and they were unable to stand the high rate of heat delivery. Trichloride of antimony has a high boiling-point and seemed to have certain characteristics of a rather simple combination, but it also decomposed. Sulphur was found to be stable in boiling, and it can exist in various forms, ranging from S_2 to S_8. Its use, however, involved various difficulties. It is viscous at any available temperature, and it is also one of the worst heat conductors known, and it almost solidifies at temperatures of 400°.

Some years ago Mr. Emmet, of the General Electric Company, began experiments using mercury as a high boiling liquid. This

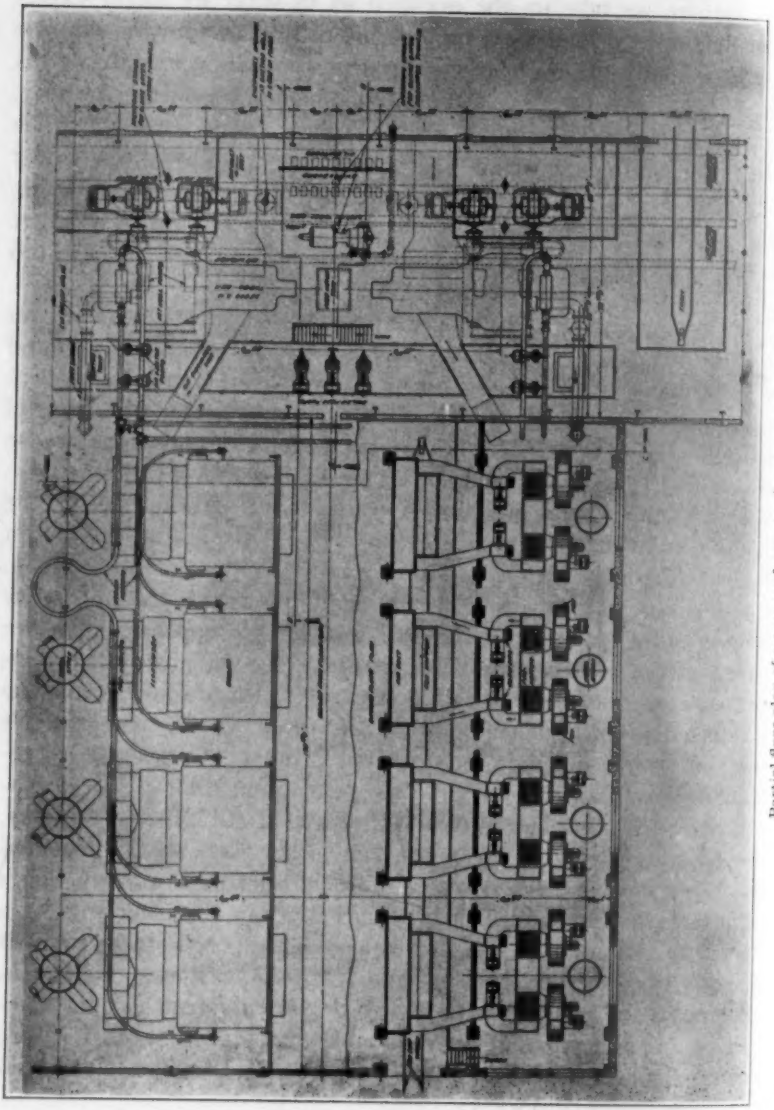
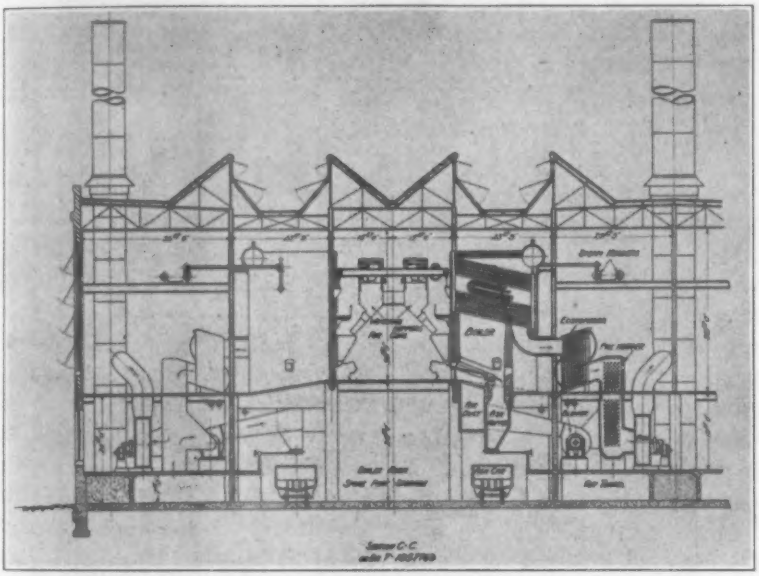


FIG. 24.

Partial floor plan of a proposed 245,000-kw. steam power plant.

metal has, for instance, a boiling temperature of 884° at pressure of only 70-lb. gauge. It has, however, a number of disadvantages. Its vapor is highly poisonous and cannot be readily detected; and also, should any leakage occur, the loss of mercury vapor would be quite expensive. However, with welded flange piping and surrounding the mercury-vapor pipes with another pipe under vacuum, there is very little danger. The early experiments of Mr. Emmet necessitated the development of a very novel mercury

FIG. 25.



Sectional view of boiler room of a proposed 245,000-kw. steam power plant.

boiler, and his experiments were on the whole sufficiently encouraging so that it was decided to build and install an actual mercury steam unit. Fig. 27 is a photographic view of such a unit as installed at the Hartford Electric Light Company's plant. Fig. 28 shows the arrangement of the boiler, mercury-liquid preheater, steam superheater, and feed-water heater. Fig. 29 shows the turbine and generator with mercury-vapor condenser, which is also the steam generator. This equipment was designed to operate with 35-lb. gauge pressure on the mercury boiler and to deliver about 1800 kw. from the mercury turbine, and to make steam at 200-lb. pressure with about 100° superheat. Fig. 28 shows clearly

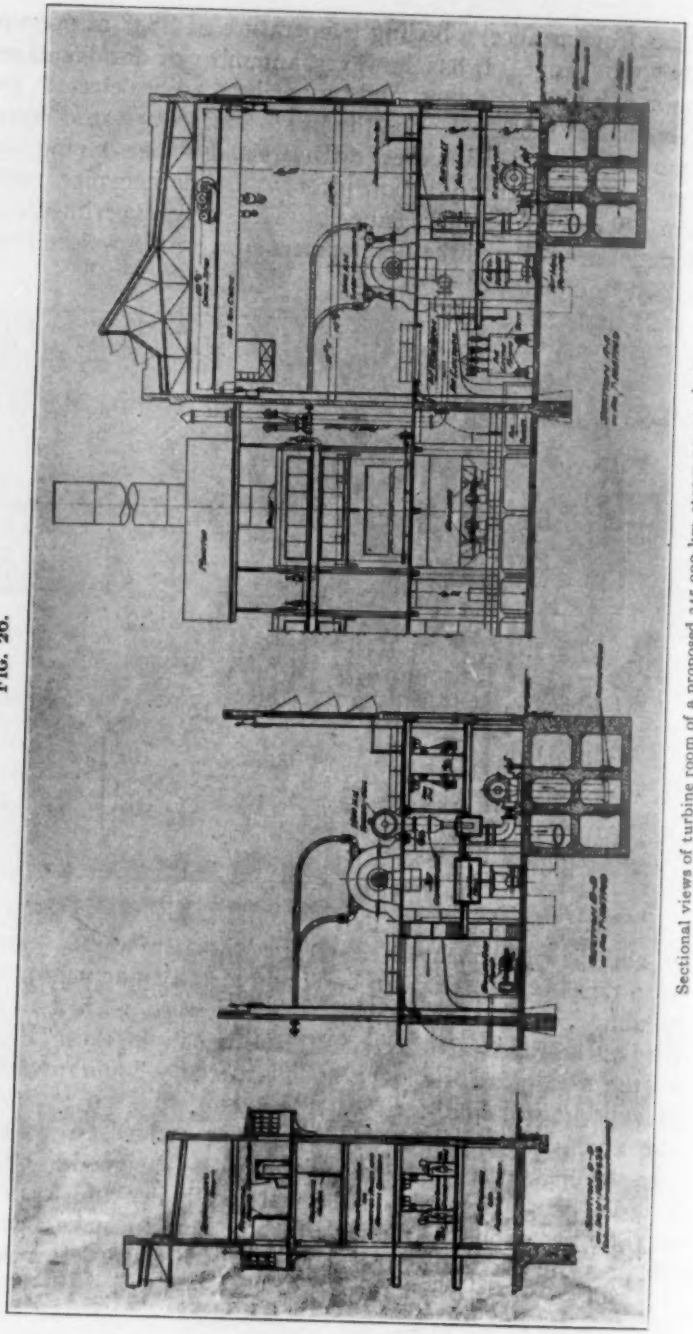


FIG. 26.

Sectional views of turbine room of a proposed 245,000-kw. steam power plant.

the path of the furnace gases, oil being used as a fuel. The furnace gases first pass through the mercury boiler, and then through the mercury-liquid preheater, from which it leaves at about 700° temperature. The hot gases then pass through the steam superheater and the feed-water heater and enter the flue at about 400°. According to more recent experience, it would have been better to have heated the feed-water by bleeding steam from the steam turbine and to use the heat in the products of combustion for preheating the air required for combustion. The mercury vapor leaving the mercury boiler passes through a governing valve to the mercury turbine, which in this case consisted of a single turbine wheel overhung on a shaft carrying the generator, and rotating in the mercury condenser space. The mercury vapor, as it is condensed in a condenser, makes steam and this steam is led to the steam superheater in the boiler previously described. The superheater steam is then used in the ordinary steam turbine plant.

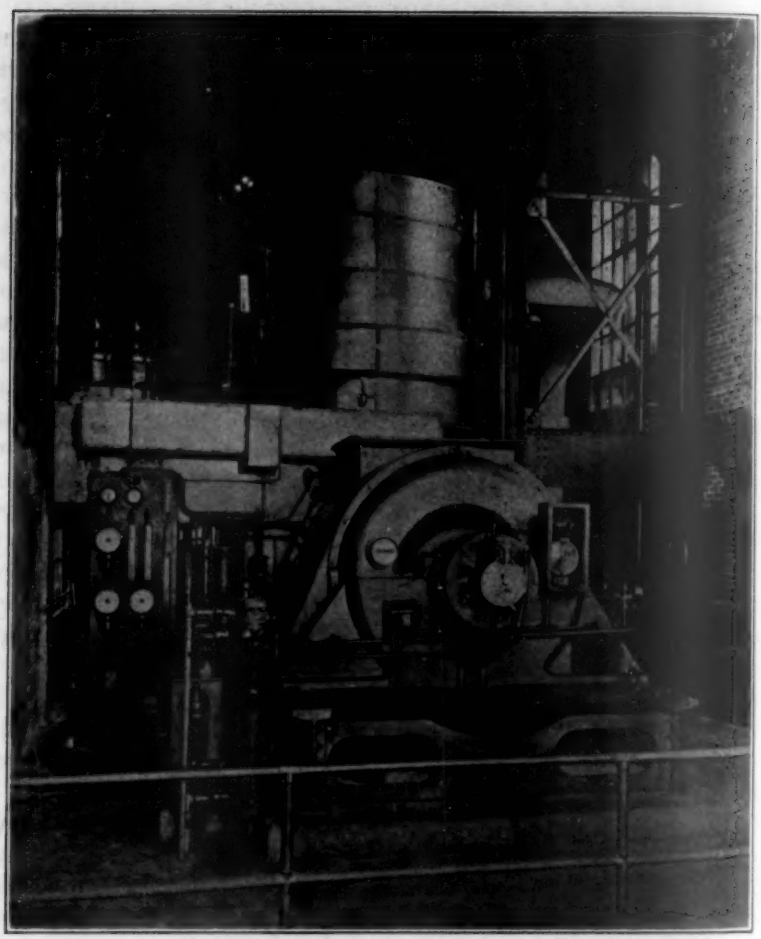
The most difficult part of this apparatus from an engineering point of view was the design of the mercury boiler. The boiling conditions of mercury are very peculiar, and are different from those of water. Mercury, for instance, does not wet the steel surfaces of a boiler, and there is a wide difference of pressures at the different heights of such a boiler. It was found necessary to have a very rapid circulation of the liquid and to have a large difference of pressure between the top and bottom of the boiler tubes, so as to prevent the boiling of the circulating liquid near the bottom of the tubes. Mercury in vaporizing in ordinary tubes acts somewhat explosively and carries the liquid mercury with it in the form of drops which are propelled forward like shot. It is therefore necessary not to boil the liquid at the bottom of the tube, but to have it vaporized near the top of the tube.

Some difficulty is experienced with mercury oxide and impurities. Mercury oxide accumulates slowly when the turbine is shut down and the very hot mercury is exposed to the oxygen in the air. The practice is, therefore, to fill the boiler and condenser during the shut-down period with some gas free of oxygen, such as illuminating gas.

After the small outfit at Hartford had run for about 800 hours during a period of several months, the mercury turbine carrying 1200 kw. most of the time and at times as much as 1500 kw., its performance was adjudged quite a success. It was also calculated

that the plant saved over 25 per cent. of fuel as compared with the steam plant there existing. It was therefore decided to go a step farther and build a new boiler capable of supplying mercury

FIG. 27.

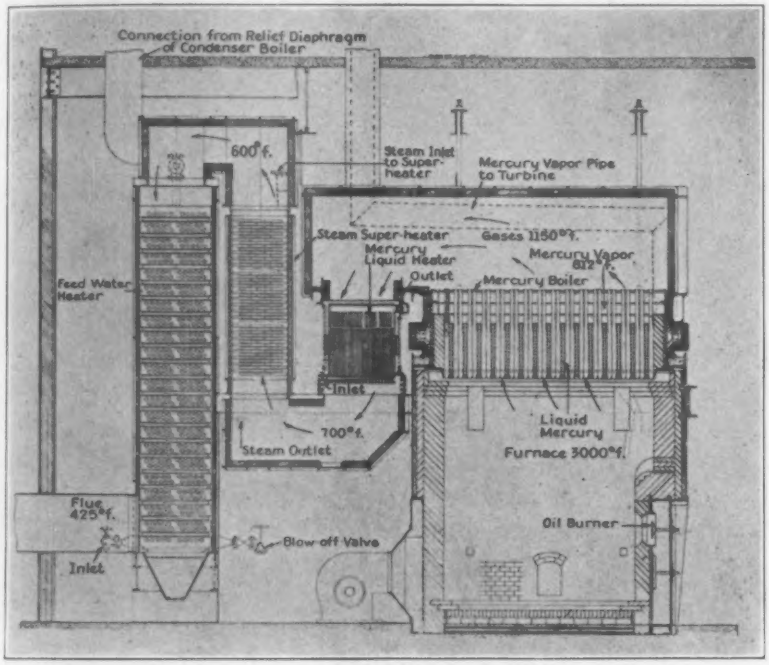


Mercury condenser, turbine and generator installed on upper floor at Hartford.

vapor at a higher pressure and temperature and to install a more efficient turbine by replacing the single-stage turbine by a three-stage turbine. Mercury may be boiled at a temperature of 884° corresponding to a pressure of 70-lb. gauge, and it can be con-

densed at a temperature of 438°, which corresponds to a mercury vacuum of 28.5″. The mercury condenser would then be capable of making steam at 285-lb. pressure with a temperature of over 400°. This steam when used in the usual steam turbine could be expanded to a final temperature of about 80° corresponding to a vacuum of 29″. It seems reasonable to expect with such an

FIG. 28.



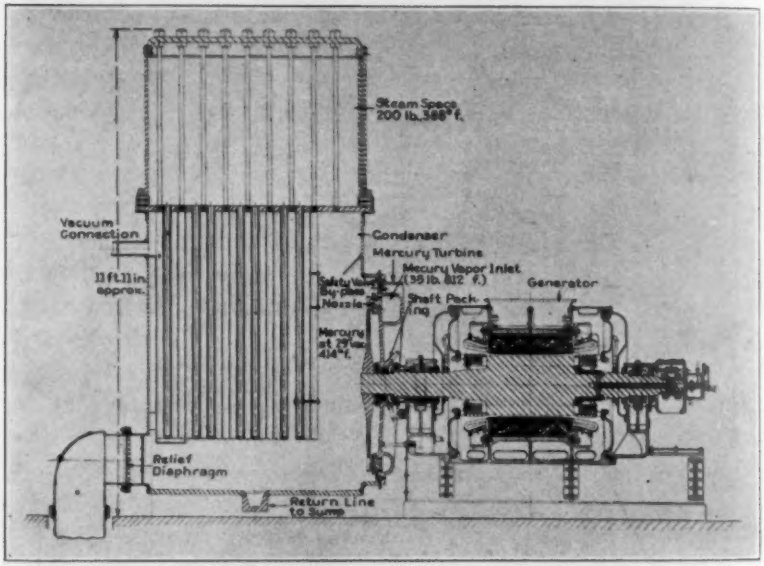
Section through boiler, heater, super-heater and feed heater.

arrangement the production of a kw.-hr. on about 10,000 B.t.u., which would be a decided step in advance in fuel economy.

Another very novel engineering suggestion will engage the minds of many engineers during the next decade, and that is, to find a practical way of using coal as a fuel while also abstracting from it many of its valuable chemical substances which are now almost universally being wasted. There are about 1800 substances that can be derived from coal. Methods are known by which coal may be distilled or carbonized. In the carbonization of coal we have three main products, coke, gas, and tar. Thus from a

2000-lb. ton of coal we get 1430 lb. of coke, 450 lb. of gas, and 120 lb. of tar. The coke is almost pure carbon; and in addition to its principal uses as fuel for power purposes, its use in the metallurgical industries (iron-blast furnace, copper smelting, lead smelting), and for the making of water-gas, it yields many valuable products, such as graphite lubricant, washing soda, silicon, carborundum, acetylene, cyamid, lamp-black, electrodes for arc lights, etc. The gas is used mainly for heat and light, but a

FIG. 29.

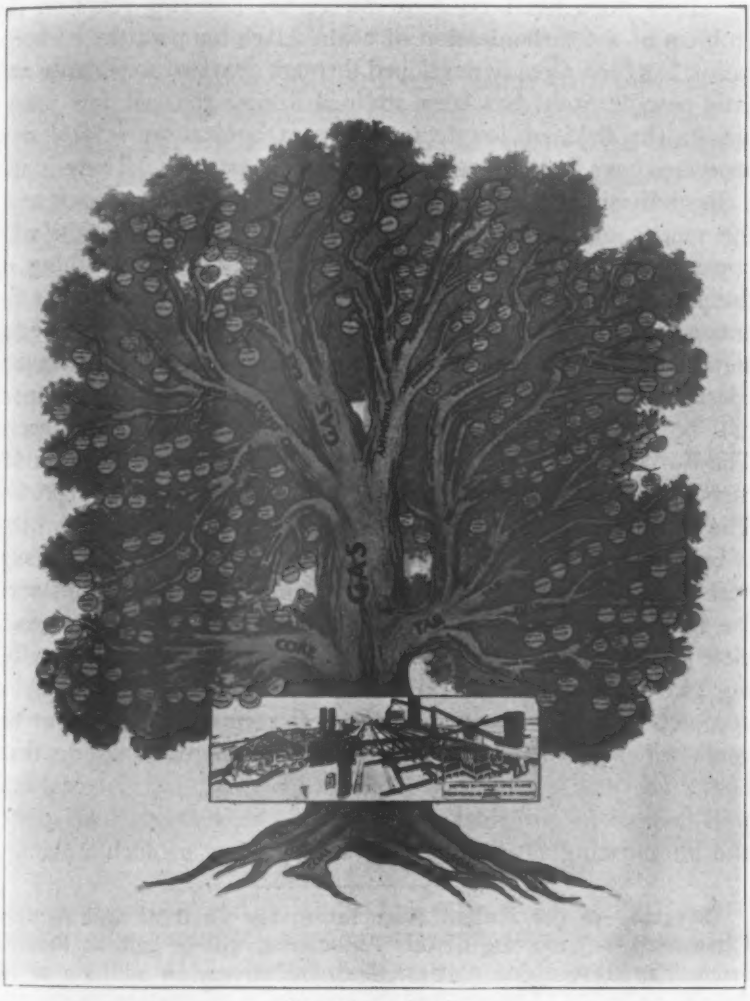


number of light oils are distilled from it, such as benzene, naphtha, etc.; besides a certain amount of cyanogen used in photography, plating, and pigment, and of ammonia which is used for explosives, fertilizer, and for refrigeration. The tar is used as pitch for roofing, paving, paints, etc.; and when properly treated it yields certain heavy oils, aniline dyes, perfumes, naphtha, acids (carbolic, picric), medicines, and materials suitable for the making of buttons or of radio parts. Fig. 30 is an interesting illustration of all the various by-products that can be derived from coal.

Suppose a so-called "by-product plant" was built in some large city in which the coal was first carbonized and these valuable products extracted. The coke could be used for power purposes,

and also sold for other uses. The gas could be used for illuminating and heating purposes and take the place of the present gas works besides permitting the recovery of ammonia and oils. The

FIG. 30.



By-products of coal.

tar would furnish a very valuable by-product. The main engineering difficulty with such an undertaking is to do all this with a reasonable cost and to find a market for all of these by-products.

If all the by-products were extracted from the coal consumed in this country the price of these by-products would be materially decreased, and we should have, for instance, an enormous amount of ammonia which could be used for fertilizers, dyes, etc.

Much work has been done during the last few years on the problem of the carbonization of coal. High-temperature carbonization has been already developed through years of experience and little new or novel has been attained during the last few years; but in the field of low-temperature carbonization several new processes have been announced during the past year. There is still a sharp division of opinion from a commercial point of view as to the merits of low-temperature distillization in connection with power generation. Undoubtedly the most noteworthy thing of the past year in America in low-temperature carbonization is the announcement of the installation of a 200-ton McEwan-Rungue commercial scale experimental retort at the plant of the Milwaukee Electric Railway, Power and Light Company. This experiment will be watched with intense interest by power plant engineers. The Ford plant has recently placed in operation a low-temperature carbonization plant from which encouraging results are reported. The Ford plant is using the Piron process. The McIntire process is being tried in West Virginia. There are other processes suggested and some are being tried experimentally, as for instance, the Doherty process, at Washington, Penna. In this plant complete gasification is carried out, and it is said that they are producing gas of nearly 200 B.t.u. per cu. ft. and are now supplying 20,000,000 cu. ft. of gas per day. It seems as if the next ten years will bring forth some very remarkable results along these lines, and what is now considered as the by-products of coal may well become its principal products and the generation of power and illuminating gas become only a by-product of such a plant.

Meeting of the Italian Association for General and Applied Chemistry.—A meeting of this Association will be held at Palermo from May 23 to June 2, 1926, both inclusive. In addition to the regular program of papers and discussions, a celebration of the centenary of the birth of Stanislao Cannizzaro will be held. Many acceptances have already been received, assuring success of the meeting. For information address "The Italian Association for General and Applied Chemistry, Via 4th of November, Rome 1, Italy."

AN ATOMIC PICTURE OF DURALUMIN AND ITS CRYSTAL STRUCTURE.*

BY

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Consulting Metallurgical Engineer, Member of the Institute.

THE investigation discussed here forms part of a general study on the constitution, heat treatment, and microstructure of duralumin, together with inquiry on the cause of the hardening-on-aging phenomenon. The object of the present paper is to give the results of some experimental work on the lattice structure of duralumin and to present an atomic picture of the alloy. The picture shown will admittedly be only a rough one. Among other items for consideration in discussing the nature of duralumin are the following: (1) Space lattice of aluminum; (2) arrangement of electrons in the aluminum atom; (3) X-ray data applying to duralumin; (4) space lattices of the elements in duralumin; (5) the $CuAl_2$ lattice; (6) sizes of the atoms in duralumin; (7) the duralumin space lattice; (8) diffraction patterns of duralumin as affected by cold work and heat treatment; (9) duralumin as a solid solution; and (10) diffusion in the solid state. These subjects are taken up below.

SPACE LATTICE AND ALUMINUM.

Aluminum has a face-centred cubic lattice of parameter 4.05 Å.U., as determined by Hull. Precision measurements by Davey [1] for metal containing 99.97 per cent. Al give the lattice constant

FIG. 1.

Diffraction pattern of cold-rolled aluminum sheet.

as 4.046 ± 0.004 Å.U. The mean value obtained by the writer on 99+ per cent. metal (high purity, commercial grade) is 4.046 ± 0.005 Å.U.—mean of measurements on 77 X-ray diffraction films.

* Communicated by the Author. Abstract of part of a thesis presented to the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Science.

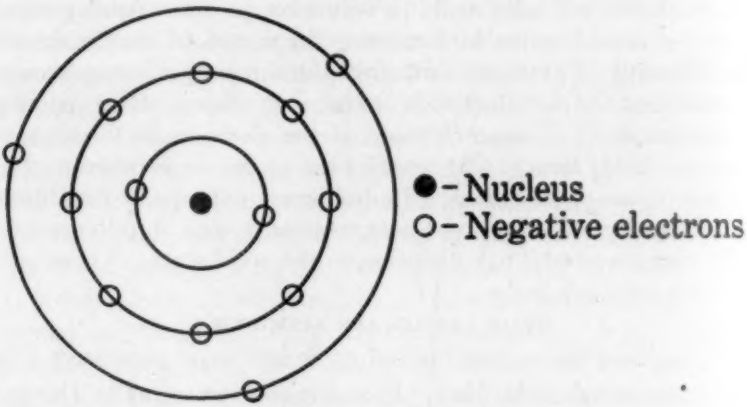
[1] W. P. DAVEY, "Precision Measurements of the Lattice Constants of Pure Metals," *Phys. Rev.*, **23**, 1924, p. 292.

On the basis of the theory, the duralumin lattice would be expected to be face-centred cubic of parameter nearly the same as that of substantially pure aluminum. Fig. 1 shows the diffraction pattern of cold-rolled aluminum sheet [2]; some lead lines appear due to the lead slit used for mounting the sample. Fig. 4 shows the space lattice of aluminum.

ARRANGEMENT OF ELECTRONS IN THE ALUMINUM ATOM.

The aluminum atom consists of a nucleus (made up of 27 protons and 14 negative electrons) and an external planetary arrangement of 13 negative electrons, considering the Rutherford-Bohr atom. Fig. 2 is a picturization of the aluminum atom,

FIG. 2.



Representation of the aluminum atom.

according to Boll. Discussion as to the arrangement of the electrons of atoms of solid elements is conjectural, but, as pointed out by Hull,[3] the tendency of the atoms of certain substances to arrange themselves like closely packed solid spheres (*e.g.*, in face-centred cubic lattices) can be imagined as due to the possibility that the electrons in their outer shells are arranged symmetrically and are so closely coupled together as to present toward neighboring atoms an essentially rigid spherical shell, having very weak residual localized forces. Symmetrical arrangement of planetary electrons is suggested in the atomic model of Boll (*cf.* Fig. 2).

[2] All diffraction patterns shown in this paper are reproduced about 2/5 actual size of the film taken.

[3] A. W. HULL, "The Crystal Structure of the Common Elements," JOUR. FRANK. INST., 193, 1922, pp. 189–216.

The distribution of the electrons for a number of atoms and the orbits of the electrons of a few atoms have been worked out by Bohr. The atomic models of Bohr and others should not be taken too seriously, since the assumptions on which they are based are open to question; moreover, such models apply for the vapor state of the particular elements. In the solid state, many of the outer orbits are too large to permit their existence.

X-RAY DATA APPLYING TO DURALUMIN.

Table I gives a summary of data regarding aluminum and the alloying metals generally present in ordinary duralumin.

TABLE I.

Summary of Atomic Data Concerning the Elements in Ordinary Duralumin.

Element.	Atomic Number.	Crystal Structure.	Lattice Parameter, Å.U.	Axial Ratio.	Distance of Closest Approach of Atoms, Å.U.	Radius of Atom, Å.U.
Al	13	Face-centred cube	4.046	....	2.86	1.43
Cu	29	Face-centred cube	3.60	....	2.54	1.27
Fe	26	Body-centred cube	2.86	....	2.48	1.24
Si	14	Tetrahedral cube (diamond form)	5.43	....	2.35	1.175
Mg	12	Hexagonal close packed	3.22 (a) 5.23 (c)	1.624	3.22	1.61
Mn	25	Unknown	...	....	...	...

TABLE I—*Continued.*

Element.	Atomic Volume.		Density, gm. per c.c.		Atomic Weight.	
	From X-ray Data, in Å.U.^{3}	From Atomic Wt. / Density.	From X-ray Data.	From Direct Determination.	From X-ray Data.	From Chemical Determination.
Al	12.48	10.0	2.69	2.70	27.18	26.96
Cu	8.58	7.15	9.02	8.89	62.84	63.57
Fe	7.99	7.11	7.88	7.85	55.62	55.84
Si	6.80	11.61	2.30	2.42	29.51	28.1
Mg	17.64	13.97	1.69	1.74	25.00	24.32
Mn	....	7.40	....	7.42	....	54.93

There is considerable disagreement as to the worth of physical values (*e.g.*, density) calculated from X-ray data. The variation between the atomic weight of aluminum as determined chemically and as calculated from X-ray data may be noted. The most

recent determination for the atomic weight of aluminum (Richards-Krepelka figures) gives 26.96, which is substantially the same as that found by the writer several years ago in calculations of the atomic weight from figures obtained in the hydrogen-evolution method for the direct determination of aluminum. Calculation from X-ray data gives 27.18.

Table II gives the distribution of the electrons in the shells of the atoms of the several elements in duralumin. The distributions

TABLE II.

Distribution of Electrons in the Shells of the Elements in Ordinary Duralumin.

Element.	Number of Electrons in Different Quantum Orbits.							Atomic Number.
	1_1	2_1	2_2	3_1	3_2	3_3	4_1	
Al	2	4	4	2	1			13
Cu	2	4	4	6	6	6	1	29
Fe	2	4	4	4	4	4	4	26
Si	2	4	4	2	2			14
Mg	2	4	4	2				12
Mn	2	4	4	4	4	4	3	25

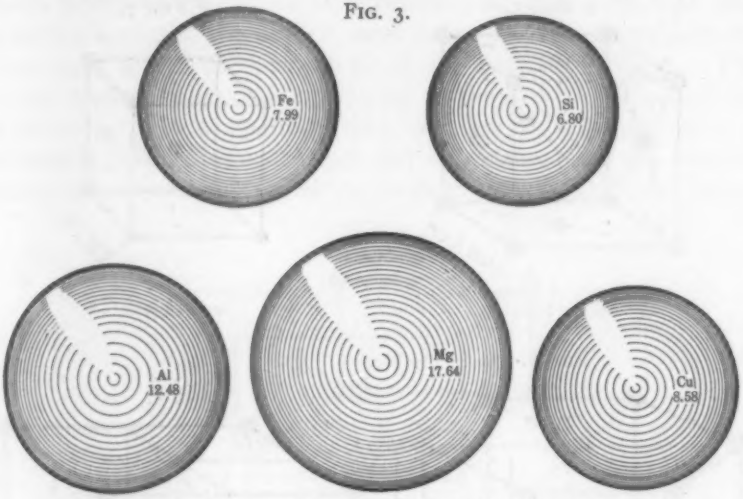
for aluminum, copper, and magnesium are those worked out by Bohr, while those for iron, manganese, and silicon were obtained by using the Bohr distribution for the sub-structures and then distributing the valence electrons arbitrarily. Thus, in the case of manganese, the arrangements for the 3- and 4-quantum orbits may be 8–7, 9–6, 11–4, 12–3, or 13–2, where the first number refers to 3-quantum orbits and the second to 4-quantum orbits. The scheme is conjectural. The number of electrons which are arranged around the nucleus of the atom and their configuration in space are supposed to govern the chemical and most of the physical properties of the atom. In alloys, it is believed that the atoms exchange electrons and by so doing increase or decrease in size. This idea is of importance in considering the space lattices of solid solutions.

SIZES OF THE ATOMS IN DURALUMIN.

The actual sizes of the atoms of the elements in duralumin vary considerably, and the consideration of atomic volume is of importance in considering solid solubility and diffusion in the solid state. If the atomic diameters for the elements in duralumin be taken as the distance of closest approach of the atoms on their space lattices, then the relative sizes of the atoms in duralumin may be represented as shown in Fig. 3. The shaded circles repre-

sent spheres of different sizes, the volumes of which represent the space occupied by an atom nucleus plus its electron shells. The relative size of atoms in a solid solution may be the predominant

FIG. 3.



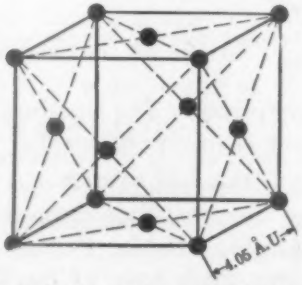
Relative sizes of the atoms in duralumin, as calculated from X-ray data.

factor in diffusion, since if an atom is too large it may be unable to diffuse at all (*cf.* Diffusion in the Solid State, below).

SPACE LATTICES OF THE ELEMENTS IN DURALUMIN.

The space lattices of the elements in duralumin have all been determined except that of manganese, and work has been done

FIG. 4.

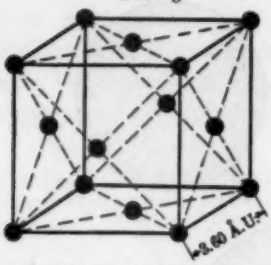


Space lattice of aluminum; face-centred cube.

on the $CuAl_2$ lattice. Figs. 4 to 8, inclusive, show the lattices of aluminum, copper, magnesium, iron, and silicon. These are

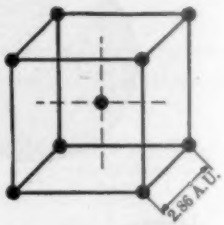
drawn to scale, a distance of ¼ inch = 1 Å.U. The face-centred cubic lattice is an atomic structure associated with great ductility and malleability, since it has very manifold symmetry and an

FIG. 5.



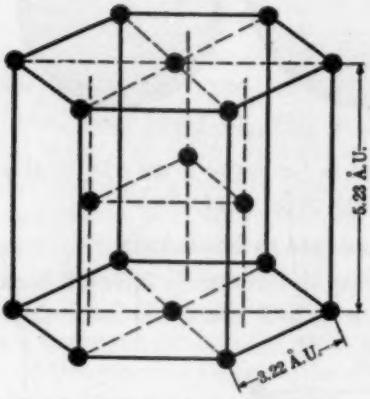
Space lattice of copper; face-centred cube.

FIG. 7.



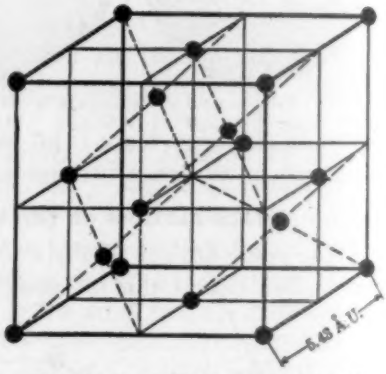
Space lattice of α iron; body-centred cube.

FIG. 6.



Space lattice of magnesium; hexagonal close packed; $\frac{c}{a} = 1.624$.

FIG. 8.



Space lattice of silicon; tetrahedral cube (diamond form).

abundance of easy slip planes. The aluminum lattice is soft, but the addition of alloying elements stiffens it.

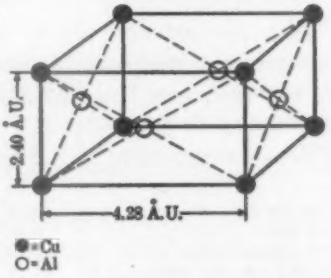
THE $CuAl_2$ LATTICE.

Of the various intermetallic compounds in duralumin (including $CuAl_2$, Mg_2Si, $MnAl_3$, $FeAl_3$, X, etc.), study by X-ray analysis has been made only of the $CuAl_2$ lattice. This lattice has been examined independently by Owen and Preston,[4]

[4] E. A. OWEN and G. D. PRESTON, "X-ray Analysis of Solid Solutions," *Proc. Phys. Soc. of London*, **36**, Part I, 1923, pp. 14–30.

and by Jette, Phragmén, and Westgren.[5] Fig. 9 shows the lattice as determined by Owen and Preston. This is a flattened face-centred lattice, without an atom in the top and bottom faces; more precisely, the lattice is tetragonal, of side 4.28 Å.U. and axial ratio 0.562, the copper atom being at the corners and the aluminum atoms at the centres of the four small faces. The $CuAl_2$ lattice structure is not found in the low-copper alloys like duralumin. The compound $CuAl_2$ does not go into solution as a molecular association of copper and aluminum since the smallest molecule of $CuAl_2$ would be too large to find room on the alumi-

FIG. 9.



Space lattice of the intermetallic compound $CuAl_2$ (Owen and Preston).

num lattice. In the arrangement of Fig. 9, the *100* planes are alternately composed of CuAl and aluminum. The molecular weight of the compound $CuAl_2$ is 117.57 and the density is 4.36. The number of molecules associated with each cell is 1 (from $n = \rho \frac{a^2 c}{M}$ = about 0.99).

Attention may be directed to the fact that, in the lattice suggested by Owen and Preston, the centres of certain of the aluminum atoms are 2.40 Å.U. apart, which is, of course, smaller than the diameter of the atom (2.86 Å.U.), and this distance is smaller than the diameter of the copper atom (2.54 Å.U.). Owen and Preston suggest that the atoms share electrons and are brought closer together than would otherwise be the case. However, if the aluminum atoms become larger by taking on electrons from the copper atoms, it might be expected that the distance between the *100* planes would be larger than that indicated.

[5] E. R. JETTE, G. PHRAGMÉN, and A. F. WESTGREN, "X-ray Studies on the Copper-aluminum Alloys," *Jour. Inst. of Metals*, 31, 1924, pp. 193–206.

Jette, Phragmén, and Westgren [6] find that $CuAl_2$ has a body-centred tetragonal lattice of sides 4.878 and 6.052 Å.U. (axial ratio, 0.806). The elementary parallelopiped is assumed to contain four molecules of $CuAl_2$. Becker [7] states that both $CuAl_2$ and CuAl are tetragonal or hexagonal.

THE DURALUMIN SPACE LATTICE.

The space lattice of ordinary duralumin has not hitherto been determined, so far as is known. Measurements were made by the writer of 86 X-ray diffraction patterns of a low-copper duralumin (containing about 4 per cent. copper) and 36 patterns of a high-copper duralumin. The actual chemical composition of the two alloys was as follows:

Element.	High-copper Duralumin.	Low-copper Duralumin.
Copper, per cent	6.05	4.03
Iron, per cent	0.79	0.80
Silicon, per cent	0.20	0.24
Magnesium, per cent	0.46	0.45
Manganese, per cent	0.63	0.59
Chromium, per cent	0.11	0.10
Aluminum (by difference), per cent	91.76	93.97

The material employed was the same as that used in the study of the effect of heat treatment on the microstructure of duralumin sheet, the results of which will appear in papers to be published later.

Samples of duralumin sheet were used for taking the diffraction patterns. These varied from No. 10- to No. 30-gage (Brown and Sharpe) and were in various conditions, *e.g.*, cold-rolled, annealed, quenched and aged, and having had a variety of heat treatments. The restricted slit and polished surface methods, described previously by the writer and Norton,[8] were used. The data show that the duralumin lattice is substantially the same as the aluminum lattice. The duralumin lattice is face-centred cubic

[6] E. R. JETTE, G. PHRAGMÉN, and A. F. WESTGREN, *loc. cit.*

[7] K. BECKER, "Die Kristallstruktur der Metalle, Mischkristallen und Metallverbindungen," *Zeit. für Metallkunde*, 15, 1923, pp. 303–305.

[8] R. J. ANDERSON and J. T. NORTON, "X-ray Evidence Versus the Amorphous-metal Hypothesis," paper before the Amer. Inst. of Min. and Met. Engrs., New York Meeting, February, 1925.

with parameter of about 4.046 Å.U. Measurements of 86 patterns of the low-copper alloy gave a mean value of 4.046 Å.U. with a rather large ± error. There may be small distortion or change in the aluminum parameter by the addition of 4 per cent. copper, but such change was not detected by the methods of experiment employed. Of course, it is understood that the addition of 4 per cent. copper to aluminum *tends to change* the dimensions of the space lattice, and anything which tends to do this must, to a corresponding extent, tend to cause distortion of the atoms or, more precisely, of their outer electron shells.

Measurements were also made of the cube parameter of the high-copper duralumin (6 per cent. copper), and here it was found that the mean value of 36 patterns was 4.042 Å.U., or slightly smaller than for substantially pure aluminum or the low-copper alloy. The indications from these data are that copper can be added to aluminum in amount up to 4 per cent. without change in the lattice parameter, but in amounts above this, within limits, the lattice contracts.

The foregoing measurements of the duralumin lattice were checked against substantially pure aluminum, copper, and sodium chloride, in experiments where the duralumin sample was placed on one side of the septum (in the diffraction apparatus) and the aluminum, copper, or sodium chloride on the other side, so that the lines from two different materials were shown on the same film.

That the addition of 4 per cent. (1.71 atomic per cent.) of copper to aluminum does not change the lattice constant of aluminum is not inconsistent with the theory. When copper atoms are added to aluminum atoms, the aluminum atoms should take up valence electrons from the copper, and since the copper atoms (Cu, atomic diameter = 2.54 Å.U.) are considerably smaller than the aluminum atoms (Al, atomic diameter = 2.86 Å.U.), the copper ions should be much smaller than the aluminum ions, and a certain number should be able to assume positions on the aluminum lattice without distorting it, in accordance with the substitution theory. According to Davey,[9] the small size of the copper atoms probably gives enough extra space to compensate for the increase in size of the aluminum in changing from atoms to ions.

[9] W. P. DAVEY, private communication.

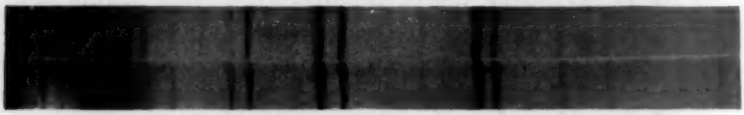
It has been shown by Jette, Phragmén, and Westgren,[10] that for the 95 : 5 aluminum-copper alloy there is no noticeable displacement of the normal aluminum lines, thus indicating that up to 5 per cent. by weight of copper can be dissolved in aluminum without affecting the aluminum lattice parameter.

Owen and Preston[11] find that an addition of 2 per cent. copper to aluminum causes no change in the lattice. Some diffraction patterns of duralumin (the low-copper alloy) in different conditions are shown in Figs. 10 to 15, inclusive.

DIFFRACTION PATTERNS OF DURALUMIN AS AFFECTED BY COLD WORK AND HEAT TREATMENT.

A series of experiments was carried out by the writer during the course of this investigation, in which the effects of cold work and various heat treatments on the pattern lines of duralumin were examined. The effect of cold work and heat treatment on

FIG. 10.



Diffraction pattern of cold-rolled duralumin sheet smooth straight lines.

the appearance of the diffraction lines given by metals and alloys in general (and including aluminum and duralumin) has previously been discussed by the writer and Norton.[12]

Fig. 10 shows a typical pattern of cold-rolled duralumin

FIG. 11.

Diffraction pattern of annealed and slowly cooled duralumin sheet; dashed lines.

sheet; the lines are straight and smooth. Fig. 11 shows the pattern given by cold-rolled sheet after heating for one hour at 500° C., followed by cooling in the furnace and air aging. The straight, smooth lines normal to the cold-worked sheet are now

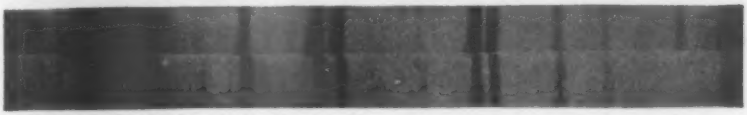
[10] E. R. JETTE, G. PHRAGMÉN, and A. F. WESTGREN, *Op. cit.*

[11] E. A. OWEN and G. D. PRESTON, *Op. cit.*

[12] R. J. ANDERSON and J. T. NORTON, *Op. cit.*

dashed and striated. This change in the appearance of the lines indicates recrystallization and grain growth. Fig. 12 shows a pattern with the lines given by quenched and aged sheet below and cold-rolled sheet above. The heat-treated sample had been soaked for one hour at 512° C., water quenched, and then fully air aged. The dashed lines typical of annealed metal may be compared with the smooth lines characteristic of cold-rolled metal. Fig. 13 shows (above) the dashed lines given by duralumin which had

FIG. 12.

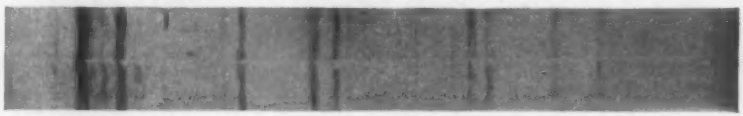


Diffraction pattern of cold-rolled duralumin sheet (above), smooth straight lines; and quenched and aged duralumin (below), dashed lines.

FIG. 13.

Diffraction pattern of annealed and slowly cooled duralumin sheet (above), dashed lines and cold-rolled duralumin sheet (below), smooth straight lines.

FIG. 14.



Diffraction pattern of annealed duralumin sheet, after loading to 12,000 pounds; wavy (dashed) lines partly straightened (*cf.* Fig. 15).

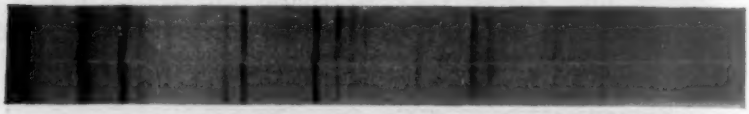
been heated for one hour at 500° C., cooled in the furnace, and then fully air aged, and (below) the smooth lines of corresponding cold-rolled alloy.

As shown previously by the writer and Norton,[13] tensile loading tends to straighten out the normal dashed lines of annealed metal, greater loads, up to certain amounts, giving greater sharpness to the lines. Fig. 14 shows the appearance of the diffraction lines of light-gage duralumin sheet (previously annealed at 500° C. and furnace cooled) after loading to 12,000 lb. per sq.

[13] R. J. ANDERSON and J. T. NORTON, *Op. cit.*

inch, and Fig. 15 shows similar sheet after loading to 16,000 lb. The higher load has caused the normal dashed lines to become sharper and smoother. The conclusion to be drawn is that greater deformation by tensile straining causes increasing fragmentation of the original grains of annealed metal.

FIG. 15.



Diffraction pattern of annealed duralumin sheet, after loading to 16,000 pounds; wavy (dashed) lines almost fully straightened (*cf.* Fig. 14).

DURALUMIN AS A SOLID SOLUTION.

The hardness of any alloy, in which the solid solubility of one constituent (the solute) in another (the solvent) is increased considerably on raising the temperature, can be increased by quenching alone or by quenching followed by aging. According to experimental observations, the hardening-on-aging effect in duralumin is due to the retention in solution of Mg_2Si and $CuAl_2$ in aluminum at the ordinary temperature in amounts in excess of the stable solubility for that temperature and the subsequent precipitation of the compounds.

The aging effect in quenched alloys is not an unusual phenomenon, and is not found only in duralumin-type alloys, as has been shown by Igarshi [14] and others. It is always observable in alloys which possess a transformation or an eutectoid change (and are quenched from temperatures higher than those at which these take place), and also in alloys in which the solubility of one component in the other increases considerably with rise in temperature. The case of a transformation or an eutectoid change may be disregarded in the present discussion. In a binary alloy system, where the solid solubility of one component in the other increases markedly with increase in temperature, when an alloy is quenched from an elevated temperature there is preserved in the cold a greater amount of the solute in solution than is normal to the low temperature. The alloy so quenched has a tendency to set free the substance dissolved (in excess of the lower temperature solubility), and this tendency causes the aging effect. Fundamental

[14] I. IGARSHI, "On the Aging Effect of Quenched Alloys," *Sci. Repts. Tôhoku Imper. Univ.*, 12, 1924, pp. 333-345.

knowledge of the constitution of solid solutions is of primary importance in consideration of the duralumin phenomenon.

In a solid solution, the solute atoms may (1) take up positions in the interstices of the parent lattice (*i.e.*, between the solvent atoms in some way), or (2) replace solvent atoms upon the parent lattice by simple substitution. X-ray crystal analysis shows that both methods are operative, but in most all cases the solid solution is built up by simple substitution of atoms. One exception is the intrusion of carbon atoms into the interstices of the iron lattice in steel. Small foreign atoms appear to be capable of intrusion into a large lattice without substitution of atoms occurring, and it is possible that in very dilute solutions of even large atoms in a solute the interstitial method may operate. The foreign atoms in duralumin replace aluminum atoms on the lattice, as may be shown by consideration of the specific volume of the alloy and the X-ray data. The parent aluminum lattice is altered not at all as to form and very slightly (if at all) by the addition of the usual alloying metals to form duralumin.

In general, large foreign atoms enlarge the lattice parameter of the solvent, while small atoms diminish it, but exceptions to this are known. Thus, according to Davey,[15] the aluminum atom, which is slightly smaller than the silver atom, stretches the silver space lattice when dissolved therein, and similarly tin stretches the silver lattice, and silicon stretches the copper lattice. Since the stranger atoms in these cases are smaller than the parent atoms, no stretching of the lattice would be expected. The enlargement of the lattice is ascribed to the fact that the dissolved metal cannot be present as atoms, but is present as ions. In the cases cited (aluminum in silver, tin in silver, and silicon in copper), the stranger atoms belong to a more electronegative metal than the solvent atoms. The increase in size of the lattice, then, may be due to swelling of the stranger atoms by transfer of valence electrons from the electropositive solvent atoms. In the case of duralumin, increasing copper (beyond 5 per cent.) shrinks the aluminum lattice. This would be expected from the theory since the copper atom is smaller than the aluminum atom, and copper is electropositive to aluminum. Generally, in solid solutions, the atoms of the more electronegative element tend to take on electrons

[15] W. P. DAVEY, "Application of X-ray Crystal Analysis of Metallurgy," *Trans. Amer. Soc. for Steel Treating*, **6**, 1924, pp. 375–392.

from the more electropositive element. According to Norbury,[16] in a solid solution, there is a certain expansion or contraction of the lattice which is large or small according to whether the "chemical affinity" (molecular solid-solution state) of the elements is large or small.

At the ordinary temperature, the atoms of a solid solution may be regarded as holding relatively fixed positions on the lattice, but when the solution is heated it undergoes expansion (cubic lattices undergo a regular and symmetrical lattice expansion). If a lattice can take up x stranger atoms at $t°$ C., then it can take up yx atoms at $t'°$ C., where y is greater than 1 and $t'°$ is higher than $t°$—for a solid solution where the solubility increases with the temperature. Thus, in duralumin, more copper (magnesium and other) atoms can be substituted in the aluminum lattice at 500° C. than at 20° C., and if this excess of solubility is preserved at the ordinary temperature, the lattice is greatly strained. Maximum distortion and maximum hardness are synonymous from the point of view of lattice conditions.

Regarding the condition of intermetallic compounds in duralumin, *e.g.*, $CuAl_2$ (Mg_2Si, etc.); $CuAl_2$ does not go into solution as a molecular association but is in solution as atoms of copper on the aluminum space lattice. $CuAl_2$ forms from groups of atoms when it exists as a separate phase.

Duralumin is a complex solid solution, containing at least copper and magnesium in solution in aluminum. On the basis of the substitution theory, the presence of one kind of solute atom in a solvent containing other solute atoms must affect the solubility of the others. Since a stranger atom in a lattice tends to cause distortion, if two different kinds of stranger atoms cause similar kinds of distortion, *e.g.*, enlargement of the lattice, they will tend mutually to diminish the solubility, and the atom which causes the least distortion will tend to throw the other out of solution. In the case of copper and magnesium in aluminum, the copper atom is smaller than the aluminum atom, but the magnesium atom is larger. Some 5 per cent. of copper when added to aluminum contracts the aluminum lattice only slightly, while 8 per cent. magnesium expands the aluminum lattice from 4.05 to 4.10 Å.U.

[16] A. L. NORBURY, "The Volumes Occupied by the Solute Atoms in Certain Metallic Solutions and Their Consequent Hardening Effects," *Trans. Faraday Soc.*, 19, 1924, pp. 586–600.

Copper hardens aluminum more rapidly than magnesium, on the basis of their relative solid solubilities in aluminum, and since the hardening is a function of the lattice distortion, the magnesium atom distorts the aluminum lattice less than the copper atom. Hence, on the basis of X-ray data, magnesium would tend to reduce the solid solubility of copper in aluminum in the ternary system aluminum-copper-magnesium. That this is actually the case has been shown microscopically by Gayler.[17]

DIFFUSION IN THE SOLID STATE.

The coalescence of $CuAl_2$ from particles of sub-microscopic size to masses which are readily seen at 200 diameters, occurring when duralumin is quenched and subsequently drawn, is a case of diffusion in the solid state. Diffusion is markedly affected by the temperature, and at some sufficiently low temperature (*e.g.*, in the case of quenched duralumin), diffusion will not take place at all. The rate of diffusion increases rapidly with increase in temperature, and hence the age-hardening of duralumin can be accelerated by drawing at a temperature higher than room temperature. From the atomic point of view, diffusion is easiest in planes in which mechanical slip is easy, *i.e.*, planes of high atomic population.

On the basis of the theory—also corroborated by microscopic examination—particles of $CuAl_2$ (and Mg_2Si) are precipitated from quenched duralumin during the course of air aging or on drawing at a moderately elevated temperature (100° C.) and these particles grow during this time. In the earliest stages of the precipitation and growth, *i.e.*, up to a certain size of particle, the hardness increases with increase in size of the particles, but with further increase in size, the hardness decreases.

The cause of diffusion and coalescence of the precipitated particles must be found in the relative volumes of the atoms involved, and reference may again be made to Fig. 3. Taking the case of the aluminum-magnesium silicide alloys; magnesium (atomic volume, 17.64) and silicon (atomic volume, 6.80) may diffuse in aluminum (atomic volume, 12.48) at the ordinary temperature precipitating Mg_2Si from solution. Such diffusion will not go on at abnormally low temperature, *e.g.*, that of liquid air. In the

[17] M. L. V. GAYLER, "The Constitution and Age-hardening of the Ternary Alloys of Aluminum with Magnesium and Copper," *Jour. Inst. of Metals*, 29, 1923, pp. 507–526.

binary aluminum-copper alloys, copper (atomic volume, 8.58) will diffuse slowly in aluminum at the ordinary temperature but much faster at 100° C., precipitating $CuAl_2$ out of a saturated solid solution obtained by quenching. That a small atom might readily diffuse (move) on the lattice of an element with large atoms is readily conceivable. The large magnesium atom can evidently diffuse in the smaller aluminum lattice at room temperature, although in the aluminum-magnesium silicide alloys it may not diffuse but the diffusion of the small silicon atom may be the primary cause of the formation of Mg_2Si and its subsequent coalescence. Diffusion will, of course, be governed also by the interatomic forces operative in the solid solution, and evidently the greater the attractive force of the stranger atoms for the parent atoms, the greater the diffusion.

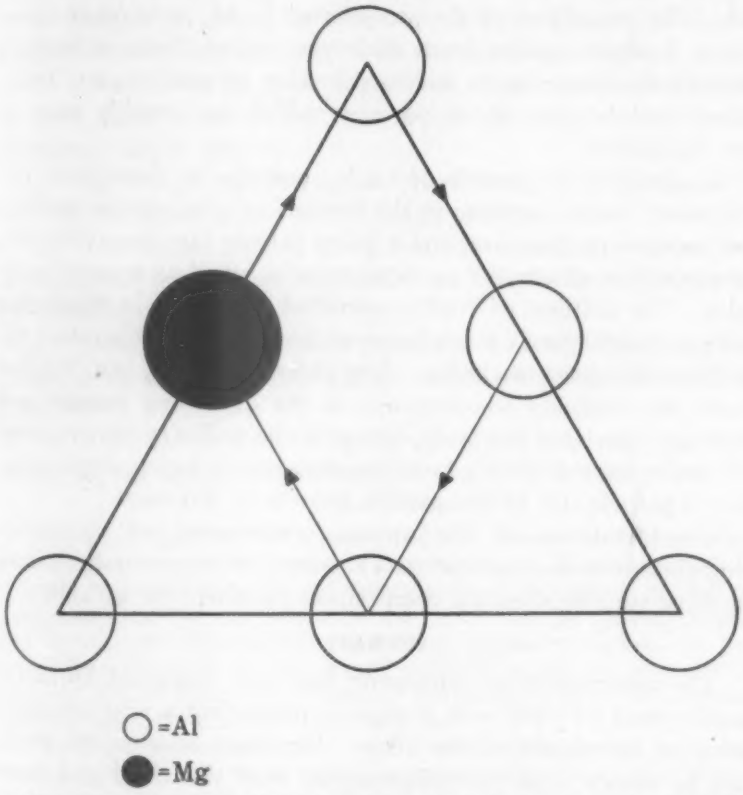
Diffusion in the solid state is explained by a scheme suggested by Langmuir, particularly for the case of large atoms on a small lattice. Langmuir suggests, briefly, that a suitable concentration gradient will produce a diffusive force moving clockwise. Movement is, then, affected by the rotation of a number of atoms simultaneously. Such rotation could take place without greatly affecting neighboring atoms or breaking atomic linkage, since the linkage would simply pass from one atom to another during the rotation. Taking the *111* plane of the face-centred cubic lattice of aluminum (this having the highest atomic population of any plane, *viz.*, six atoms), the sketch of Fig. 16 may be noted. As cut through a unit cell, the *111* plane is an equilateral triangle, and for convenience here there is shown one such triangle. Aluminum atoms are indicated by open circles and a magnesium atom (larger) by the black filled circle. The arrows indicate how three aluminum atoms and one magnesium atom can move clockwise under diffusion forces.

It should be added that Rosenhain [18] suggests that diffusion takes place in a solid solution by a process of internal slip. On the basis of the substitution theory, the presence of a stranger atom in a space lattice sets up local intense stresses in its vicinity, and since at high temperature the stress can be relieved by the occurrence of internal slip, such slip might be expected to occur. Such slip might need to be only one atomic slip, *i.e.*, a row of

[18] W. ROSENHAIN, "Solid Solutions," *Trans. Amer. Inst. of Min. and Met. Engrs.*, 69, 1923, pp. 1003–1034.

atoms might move forward a distance equal to the parameter of the unit cell. It is also suggested by Rosenhain that solute atoms which cause the greatest amount of distortion in the solvent lattice should exhibit the most rapid rate of diffusion because the stresses

FIG. 16.



Diagrammatic representation of diffusion of magnesium in the *111* plane of the aluminum lattice.

in the lattice tending to cause slip would be greatest for such atoms.

In regard to the matter of particle growth owing to diffusion; $CuAl_2$ (and Mg_2Si) precipitates first in sub-microscopic particles which subsequently grow in size. It is of interest to consider how large these particles may be. A particle which is just sufficiently small to be beyond the resolving power of the microscope may be considered. The smallest distance that an objective of aperture

1.40 (2 mm. oil immersion) can resolve is 0.00015 mm. From this, a particle of Mg_2Si or $CuAl_2$ at least 0.0002 mm. long could be distinguishable in a duralumin matrix. A particle of $CuAl_2$ ($a = 4.28$ Å.U.) which is 0.0002 mm. long would contain about 94,000 molecules considering two molecules of $CuAl_2$ to a unit cell. The actual size of the precipitated $CuAl_2$ particles in duralumin doubtless varies from molecular nuclei (two molecules) through the range up to microscopic size (around 94,000 molecules) and beyond up to particles which are readily seen at 200 diameters.

Coalescence or growth of $CuAl_2$ particles in duralumin (by diffusion) means decrease in the number of precipitated particles and increase in their size, and a given particle can grow evidently by absorption of smaller particles even as small as several molecules. The softness of freshly quenched duralumin is ephemeral, since on standing only a few hours at the ordinary temperature the hardness increases markedly. Any excess of $CuAl_2$ (or Mg_2Si) above the solubility concentration at the quenching temperature does not enter into the precipitation at the ordinary temperature, but such excess doubtless favors coalescence on aging since variation in particle size favors particle growth by diffusion.

Considerations of the atomic constitution of duralumin (together with microscopic data) point the way to selection of the most suitable chemical composition for this type of alloy.

SUMMARY.

The constitution of duralumin has been discussed from the atomic point of view with a view to presenting a true representation of the nature of the alloy. The main conclusions which may be drawn from the experimental work described and from theoretical considerations are the following:

1. Aluminum has a face-centred cubic lattice of parameter $4.046 \pm$ Å.U.

2. Representation of the aluminum atom, according to Boll, shows three planetary electron orbits, the first containing two, the second eight, and the third three electrons.

3. Summary is given of the X-ray data applying to the elements in duralumin.

4. Representation is made of the actual sizes of the atoms of

the elements in duralumin; such representation is useful in considering diffusion in the solid state as an atomic phenomenon.

5. Representation is made of the space lattices of the elements in duralumin.

6. The $CuAl_2$ lattice is discussed.

7. Duralumin has a face-centred cubic lattice of parameter 4.046±, substantially identical with the aluminum lattice.

8. An addition of about 4 per cent. copper to aluminum has no effect upon the lattice, but about 6 per cent. copper contracts the aluminum lattice slightly.

9. The foreign atoms (copper, magnesium, etc.) take up positions on the aluminum lattice by simple substitution.

10. The effects of cold work and heat treatment on the lines in diffraction patterns of duralumin are discussed and illustrated by crystallograms.

11. Duralumin, as a solid solution, is considered from the atomic point of view, and the hardening-on-aging phenomenon is discussed.

12. The precipitation of $CuAl_2$ (and Mg_2Si) from quenched duralumin on aging is considered on the basis of diffusion.

Annual Report of the Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, July 1, 1924, to June 30, 1925.—In the magnetic-survey work carried on during the year especial emphasis was placed on the getting of data that would give information concerning secular variation. It has been found that observations should be made at shorter intervals of time and also at stations separated by shorter distances. This is true for both magnetic and electrical surveys.

The Department coöperated with several governmental organizations in its work. Of these were South Australia, New South Wales, Argentina, Canada, Scandinavia and the United States. In turn assistance was received from observatories all over the world. The non-magnetic vessel, the *Carnegie*, has remained peacefully at a wharf in Washington, but future cruises are under consideration, because a real need for additional oceanic data has arisen. Two cruises, each of 90,000 miles' length and thirty-three months' duration, have been outlined. The appended map shows that the entire Atlantic and Pacific Oceans have been traversed by either the *Galilee* or the *Carnegie*. The Indian Ocean has not been so well covered. For only a short distance in the southern hemisphere were observations taken nearer to the pole than 60° S. latitude. In the northern hemisphere the *Carnegie* on its third cruise reached Spitzbergen at about 80° N.

Thus the parts of the ocean unexplored magnetically up to the present time by the Department are the waters south of 60° S. and the seas to the north of Siberia and North America. Unfortunately funds appear to be wanting with which to put the *Carnegie* into active service. One perhaps minor but certainly interesting outcome of the former work done on the *Carnegie* and on the islands themselves is the establishment of a magnetic anomaly in the Bermudas. "The average annual rates of change in declination at two points but a few miles apart differ by as much as 2′."

The field work was conducted in North and South America, Australasia, Siberia, Greenland and on islands in the Atlantic Ocean. In South America, Mr. J. T. Howard made his way on mule-back, in mail-launch and canoe. Another observer visited the Falkland Islands and Tierra del Fuego. Directions for several proposed Arctic expeditions were prepared so that magnetic and electric observations can be made. "Secular-variation data as well as continuous registration data for eight months in terrestrial magnetism and electricity at a far northern observatory have been obtained through the coöperation effected with Doctor McMillan's Expedition." It may well be doubted whether such opportunities for adventure in physics as are available in the Department of Terrestrial Magnetism can be discovered elsewhere in the world.

The daily work of the observatory goes on in Watheroo, Australia, in Huancayo, Peru, and in Apia, Samoa.

We turn now to the work, experimental and theoretical, centring in the Laboratory in Washington. "Several recent investigations have conclusively shown that the earth's magnetic field has an appreciable effect on the electric waves used in wireless transmission, and that there is a distinct relationship between terrestrial magnetic disturbances and certain radio phenomena." Acting in conjunction with other government agencies and with private enterprises, the Department has taken up the study of the Kennelly-Heaviside layer, that suppositious region above our heads that conducts electricity and reflects electric waves. Two of the investigators from the Department, collaborating with the Naval Research Laboratory, got clear indications of its existence at a height of 50 or 100 miles above the surface of the earth.

Other subjects that have received attention in the course of the year are the analysis of the magnetic field of the earth, correlation between solar activity, atmospheric electricity and terrestrial magnetism, annual variation of atmospheric electricity, the plotting of isoelectric charts for the oceans and of magnetic charts for the polar regions. Experiments extending to 2400 atmospheres have shown that for nickel at least pressure has only a small effect on the temperature at which magnetism practically disappears.

Year after year the report of the Department of Terrestrial Magnetism is a source of just pride to all who feel an interest in the scientific achievements of the United States. G. F. S.

LIGHTNING.*

BY

N. ERNEST DORSEY, Ph.D.

IN ADDITION to ball lightning, which appears to be in a class by itself, there are a number of other well-attested effects produced by lightning which do not accord satisfactorily with the opinions commonly accepted. It appears that certain quite dissimilar classes of these phenomena can be coördinated with one another and with certain experimental data; but such correlation necessitates a revision of our commonly accepted ideas. It is to this correlation and revision that I wish to direct attention.

Of the classes of phenomena referred to, the following may be taken as typical: (1) Lightning may strike down into a cavity which is surrounded by high conductors which are well earthed. (2) It may knock a section out of a wall without disturbing the portions either above or below the hole. (3) It may pierce a hole through a pane of glass, and do so even when the pane is small and forms a window in what is essentially a closed metallic surface. (4) In dry sand, it may form long fulgurites.

As an example of the first, we may take the case of Botham Bar, where it "struck down into a cavity surrounded by high buildings with lead roofs, iron rain-water pipe, and an iron portcullis, to get at a street bracket 11 feet 6 inches above the pavement."[1] Or we may take the case, recently described,[2] of a tree nearly fifty feet tall, which was closely guarded on one side by a building about sixty feet tall and on all other sides by trees approximately its own height, but was nevertheless struck at a point only eight feet from the ground. In both of these cases, the electric field at the point struck and before the advent of the stroke, must have been very weak; the inductance of the path leading to this point could not have been essentially less, and most probably was greater, than alternative paths leading to the tops of the adjacent high objects; and there is no reason for believing that along the path followed in this weak field the medium was in any way significantly "weaker" than elsewhere. The ideas commonly accepted do not accord with the observed fact that these points were struck.

* Communicated by the Author.

One of the most striking illustrations of the second is the damage which was done to St. George's Church, Leicester, in 1846, when a section, some fifty feet long, was knocked out of the spire with so little disturbance of the upper portion of the spire that it fell vertically downwards into the lower portion, carrying away all the floors and damaging a foundation arch, but not destroying the walls.[3] Or we may take the "singular case" described by A. P. Chattock,[4] in which a hole was knocked through a garden wall. Practically all the bricks fell on the same side of the wall; the top row of bricks was left intact, bricks were knocked from the next two rows, and a few in the fourth row were damaged. All effects simulating an explosive action are commonly explained as arising from gases or vapors liberated by the current, or from a rapid heating along the path of the discharge; they are regarded as arising from something akin to a boiler explosion occurring where the damage was done. But a boiler explosion is not a directed effect; the explosive force is exerted in all directions. Were this the explanation, then the top of the spire would have been toppled over; the top row of bricks would have been dislodged from the wall. The effects described could not have been so caused, though they might have been caused by a violent explosion at a point in the air by the side of the wall; each must have resulted from a very definitely directed blow. The section of the spire was knocked out from under the top, as one coin may be flipped from under another. The wall was damaged as though by a cannon ball.

Probably the most noted illustration of the third type of effect is found in M. Melsens' description[5] of the striking of the Antwerp Railway Station in 1865. "A few words are sufficient to show the peculiarity of the phenomenon. The lightning crossed a square of glass and produced in it a hole similar to that which would be produced by a projectile thrown upwards from below at a slow rate, say from 30 to 50 metres per second, and travelling from earth towards the sky; the edges of the hole were melted. . . . It is extraordinary for lightning to pass, without any conductor, through a square of glass 4 millimetres in thickness (forming a parallelogram of 0.35 by 0.38 metre, having angles of 83° and 97°). The opening produced was at some centimetres from iron and lead conductors, which were in perfect metallic communication with all the iron of the station. . . . But the

anomaly does not stop there; to the right and left of the glass roof in which the broken pane was, the covered platform of the station has a roof of zinc No. 13, presenting to the lightning a surface of 3000 square yards; . . . the three tall rods of the lightning conductor are in immediate metallic contact with this zinc, and with the conductor, and the whole is connected to twenty-eight hollow columns, serving to carry off the rain-water." [6] Lodge states that he mentions nineteen flashes which present some analogy to this one. The path through the glass to earth was certainly not the easiest one; the self-induction of the path followed could not have been significantly different from that of any one of many possible paths leading to the adjacent metal only a few centimetres distant; and prior to the flash the field immediately above the glass must have been weak, much weaker than that above the more elevated portions of the station. Below the glass, the field must have been essentially zero. There was nothing to tempt a conduction current to pass through the glass.

Fulgurites, the fourth type, are described thus: "Fulgurite is the name given to rocks which have been fused on the surface by lightning, and to characteristic holes formed by the same agency. When lightning strikes the naked surfaces of rocks, the sudden rise of temperature may produce a certain amount of fusion, especially when the rocks are dry. . . . A thin glassy crust, resembling a coat of varnish, is formed; its thickness is usually not more than one-eighth of an inch. . . Another type is commonest in dry sands and takes the shape of vertical tubes which may be nearly half an inch in diameter . . . and several feet long." [7] "Externally they are rough, somewhat whiter than the surrounding sand; inside they are enamel-like, from the glassy surface of fused silicon. . . . After following one for a length of 10 feet along its course, there appeared no indication of a change in size, and further excavation was impracticable." [8] Even though, for some unexplained reason, the current through the air reaches the sand in a very restricted area, why does it not spread through the sand in the manner characteristic of conduction currents, instead of remaining restricted to a narrow tubular path? Although not impossible, it is scarcely probable that the properties of the sand along such a long, relatively straight, narrow tube differed very significantly from those of the adjacent portions.

It is not at all clear how a conduction current could have confined itself to such a tube. And why is the fulgurite a tube, rather than a rod? The accounts do not suggest that the fused material ran down into the sand; if it did, the fulgurite would terminate in a large fused mass, representing the entire amount of sand which originally filled the tube. Nothing of this nature is suggested by the reports. Rather, they suggest that the molten material might have been driven laterally from the tube. Such a lateral expulsion could scarcely have resulted from the expansion of heated gases, for these permeated the entire mass. Their expansion might have caused the melt to froth and overflow; they might have given rise to a porous, lava-like rod of material, but scarcely to a hollow cylinder.

For the present, fulgurites will not be considered further. In each of the other three types, the path ignored, in large measure, the local field existing before the arrival of the stroke, and the stroke was delivered to a very definitely circumscribed area. In the second and third cases, it delivered a definitely directed and, in the second, a powerful blow. Of the types of current studied in the laboratory, only one possesses these characteristics. That one is a beam of cathode-rays.

That something analogous to a beam of cathode-rays should be associated with a lightning stroke is not surprising. Early in this century, Sir J. J. Thomson and J. S. Townsend, each, called attention to the fact that a spark does not pass unless at some point the field is of such an intensity that it will confer upon a free electron, in the interval between two collisions with the molecules of the gas, such a velocity that it is able to dislodge an electron from the molecule with which it collides. But if a spark cannot pass at the point A unless free electrons have this critical velocity at that point, then the same must be true at every other point of its path. That is, the spark marks the trail of electrons flying with such velocity that they ionize the gas. The flying electrons ionize the gas; the laggard electrons combine with the resultant positive residues, and so give rise to the brilliant flash; the ions make a conduction current of the usual type possible if the field is maintained, but this current is distinctly subsequent to the spark.

At low velocity, an electron can not ionize a molecule by colliding with it. As the velocity is increased, it presently reaches

such a value (of the order of 3.6×10^8 cm. per second) that it can ionize the molecule if the collision occurs in a favorable manner, the number of ions produced per centimetre of path will, however, be small. As the velocity is increased further, the number of ions produced per centimetre of path increases very rapidly, until presently an ion is formed at each collision. At atmospheric pressure, the number of ions now produced per electron per centimetre of path is about 15,000. A further increase in velocity will not increase the number. Until this stage is reached, an electron moving with a velocity greater than that characteristic of the field will, on the average, expend energy more rapidly than it is conferred by the field, and its velocity will decrease. But at greater velocities, the number of ions produced per centimetre decreases as the velocity is increased—at 1.5×10^9 cm. per second, the number is only 25 per cent., and at 1.5×10^{10} cm. per second it is only about 2 per cent. of what it is at 3.6×10^8 cm. per second. Hence, in fields corresponding to these high velocities, any increase in velocity is not only retained, but is enhanced; the velocity tends to increase explosively.

If the field were maintained constant at such a value that an electron was dislodged at each encounter, and if the several electrons exerted no mutual repulsion, then an elongated swarm of electrons would be produced. At the end of the sixtieth encounter, the swarm would contain over 10^{18} electrons; which represents a gross charge of over $\frac{1}{8}$ coulomb. At this velocity (3.6×10^8 cm. per second) sixty collisions would occur in a distance of about 0.04 mm. But there is mutual repulsion between the individual electrons, hence the swarm will tend to spread in all directions, but more especially in the direction of its motion; it will draw out into a dart. The leading electrons will be subjected to the repulsion of the trailing ones, as well as to the field arising from other causes; their acceleration will be augmented; they will gain energy at the expense of the trailing electrons. Instead of a very great number moving at a moderate velocity, there will be a smaller number moving with a correspondingly greater velocity. And we have seen that, if the field is maintained, any increase in velocity will, in this region, result in an explosive increase in velocity. Hence, in intense fields, darts of electrons advancing with a velocity approaching that of light are to be expected. At such velocities, the mutual repulsion of the

electrons is greatly reduced in the direction of the line of flight, and the attendant magnetic field in great measure compensates their lateral repulsion. At these velocities, the dart may be relatively compact. Having once acquired a high velocity, a much weaker field will suffice to maintain the motion, and in virtue of its own momentum, aided by a rocket-like propulsion, a high-speed dart may proceed for a considerable distance even through an adverse field. As the velocity of the leading electrons decreases, the trailing ones overtake them, and the rocket effect is increased; the leaders are speeded up at the expense of the trailers. At such high velocities it is probable that nearly all the ionization is produced by the leading electrons; the trailers passing, in general, unimpeded through the gaps so formed. Thus a still weaker field will suffice to maintain the motion.

But presently the velocity of the leading electrons is so reduced that they lose their ionizing power, and combine with the molecules to form ions. This combination causes their velocity to decrease abruptly. The trailing electrons drive into them, and likewise have their velocity abruptly reduced. Where the dart stops, there is a very rapid building up of a negative charge and of a surrounding electric field, which presently may attain the critical value characteristic of ionization by collision. Then, if the trailers continue to pour in at such a rate as to maintain, or to increase, the intensity of the field notwithstanding the production of positive residues, a new dart will form. The direction of this dart will, in general, be inclined to that of its parent. As a result of the mutual repulsion of the assembled electrons—now ions—there will be formed in the air a region of rarefaction, surrounded by a shell of condensation in which the pressure may be very great, as the condensation is formed with extreme rapidity. The positive residues produced by the new dart will stream to the rear and neutralize the accumulated negative charge, and the rarefaction will collapse. Where the old dart stops, there is an explosion. This accords with the observation of Trowbridge,[9] that there is an explosion wherever a spark changes its direction. He suggested that the characteristic rolling sound of thunder might be the result of such explosions occurring at various distances from the observer; the suggestion seems to be well founded. The sudden stopping of the electrons transfers a great amount of kinetic energy to the molecules; some of this will appear as heat,

and will increase the effects just described; but whether the amount of this increase is significant, as compared with the total, is questionable.

The direction of flight of the new dart will depend both upon the asymmetry of the resultant field and upon the positions, at the proper instant, of the free electrons which are available for its initiation. If the asymmetry is great, the direction of flight will probably approximate to the direction of the steepest potential gradient. Unless the old dart is so long that it is able for a time to supply electrons faster than the positive residues of the new dart are formed, it is improbable that a second dart of any considerable magnitude will form. But if the old dart is long, and especially if the asymmetry of the field is not great, there will probably be more than one dart. If many free electrons, well distributed, are available at the proper instant, and if the field is not too asymmetric, there will be many darts, shooting in various directions. I have been told that such "shot-gun" lightning strokes occur. If the point at which the old dart stops is near an extended conductor, especially if the conductor is earthed, the line of maximum gradient will usually † lead to the conductor, and usually the dart will fly in that general direction. Thus a horizontal stroke may result.

A good illustration of the formation of nearly horizontal and of multiple darts is afforded by the case I recently described.[2] The tree had three punctures lying in the same vertical line. The topmost, and much the most prominent, appeared to have entered the tree nearly horizontally, but, as the wood was splintered and much of it missing, the exact direction is uncertain. The next, 13.5 inches lower, entered at an angle of about 50°; and the third, 12 inches lower, at an angle of about 28° with the vertical. Three inches lower, the bark was charred at a fourth spot. Four darts were registered. Assuming that the topmost puncture was truly horizontal, the first two indicate that the parent dart stopped

† It will not necessarily lead to the conductor unless in the interval between the arrival of the old dart and the starting of the new one the electrical carriers in the conductor can readjust themselves in accordance with the field produced by the advent of the dart. It is not at all certain that any very significant readjustment can occur in this short interval, especially if the carriers are massive electrolytic ions. If there were no such readjustment, the gradient would be simply the resultant of the preëxistent field and of the field set up by the old dart. This resultant might not lead to the conductor.

16 inches from the tree; the first and third indicate 13.6 inches; and the second and third indicate 11.5 inches. These values agree as well as the data warrant. If, as is entirely possible, the actual direction of the topmost dart was upward at an angle of 18° with the horizontal, then the three directions pass through a common point, 11.5 inches from the tree. That is probably the place at which the parent dart stopped.

It will be noticed that, each time a dart is stopped, an effect exactly analogous to that produced by an hydraulic ram results. Between the point where the lightning stroke is initiated and that where it strikes, there is a battery of such rams connected in cascade. As a result of this and of the rocket-like propulsion of the dart, the latter point may, under favorable conditions, acquire a negative potential which exceeds that of the former.

When a high-speed dart strikes a resisting object—such as a rock or a tree—it will deliver a powerful blow, and the electrons composing it will penetrate a certain distance before their velocity is reduced sufficiently to permit them to become attached to the molecules. When such attachment occurs, the mechanical and electrical stresses will build up rapidly, as already described; but in the present case the effect will be greater than before, (*a*) because the dart may be relatively compact, and (*b*) because as the velocity is reduced the mutual repulsion of the electrons, for a given distribution, rises from a smaller value to that characteristic of static conditions. At the same time, such conduction current as the object can yield will build up as rapidly as possible under the circumstances. The heat, produced by the conduction current and by the deformations resulting from the stresses produced by the dart, will tend to increase the stresses; but both the conduction current and the rise of temperature are distinctly delayed effects. The first is delayed by its inertia, and the second occurs only as the ordered molecular, or ionic, motion delivered by the impulse, or by the field, becomes transformed, by many molecular encounters, into the disordered motion characteristic of heat. It seems futile to discuss the relative effectiveness of the rise of temperature in producing the stresses which actually occur, until after we know more regarding the various time intervals which are involved. Personally, I am inclined to believe that many results to which a thermal origin has been ascribed were due mainly to stresses of an electrostatic nature.

If the object struck is the bare surface of an extended rock, or a sheet of glass, the surface will merely be fused if the dart is not strong; if the dart is strong, so that many electrons are driven into the material, the stresses of electrostatic origin will cause flakes to break off from the side against which the dart impinged. Some of these flakes may be so highly charged that they will be reduced to powder. Thus a cavity is formed. As the dart drives on, the cavity is deepened, the débris being driven out around the dart, sand-blasting the sides of the channel as it goes. So the glass is penetrated, and the holes described as "smoothly bored" may be made in rock. In the case of glass, there seems to be evidence of fusion in all cases; I would expect the same to be true for the holes in rocks, but there seems to be no way in which such holes can be produced by fusion alone, and even fusion, followed by removal by electrostatic repulsion, seems scarcely tenable. The way the flakes are torn off makes the hole produced in a sheet of glass resemble one made by a projectile impinging upon the side opposite to that struck by the dart (*cf.* the case of Antwerp Station). If the dart strikes a bed of sand, similar effects will be produced; but, owing to its difference in structure, more material will be driven laterally, higher temperatures ‡ will be reached, and secondary darts may be formed. In all these cases, there is a continual removal of charge after a certain potential is reached. If, however, the dart strikes an object such as a tree, into which the electrons penetrate deeply before becoming attached to the molecules, there can be no such continued escape, and the charge builds up until the object explodes.

The records of lightning strokes indicate that the cross-section of a dart is small, frequently less than 2 mm. in diameter. It seems improbable that any very extended damage would result from the mere mechanical impact delivered to such a small area, even though the impulse were great. But if a dart stopped quite near an object, the latter would be subjected to the compressional wave from the explosion which occurred where the dart stopped,

‡ It seems probable that such darts as here pictured would disrupt some of the molecules with which they collide, would strip some of the atoms free of electrons, and might even smash some of the nuclei. The high temperature evidenced by the fusion of quartz in fulgurites might arise, at least in part, from the reconstruction of the systems so disrupted.

and it might be subjected to a perfect shower of darts covering an extended area. The latter would greatly increase the effectiveness of the direct blow, and each would increase the extent of the damage. It is probable that the damage to St. George's Church and that to the garden wall were caused in this manner.

As the charge carried by the dart is delivered abruptly, violent surges and oscillations will be set up in neighboring conductors, as well as in the body struck, and phenomena of the kind so clearly described by Sir Oliver Lodge will necessarily result. There may also be true oscillations along the path of the flash. Under favorable conditions, this path will be essentially a linear conductor which is suddenly injected into a longitudinal field; it will act as a linear oscillator, giving out rapid and highly damped oscillations. As the cloud is such an execrable conductor, it is probable that the conduction currents in it will contribute very little to these oscillations.

When the dart speeds from the cloud to the ground, it will frequently strike where the field is weak. When the stroke is in the reverse direction, it will always start where the field is intense. Where the dart starts there is no wave of explosion, no mechanical blow is struck, and, as compared with the action of an impinging dart, the electrical charges are delivered slowly. If the dart starts from a good conductor which is earthed, the current through that may be great; if from a poor conductor, the current through that will be small, but the body may become highly charged, and the mutual repulsion of the constituents of this charge may rip off the outer layers of the body.

From upward strokes—darts flying upwards—high, well-earthed conductors will probably protect a certain area quite completely. From downward strokes, nothing, except a completely closed, and probably a rather massive, metallic shell enclosing the object, will insure its protection; but an enclosure of metallic netting will greatly reduce the risk, if the meshes are not too large. Protection could also be secured if it were possible to lay down, at a suitable height, a blanket of positively charged air, so that the dart would spend itself by running through a weak field; but wind makes it impossible to maintain such a blanket under every condition.

But can such darts form under the conditions which actually

exist in thunderstorms? The conditions seem to be favorable. What is required is an intense field which can be maintained at the dart, although that leaves a dense trail of positive residues. The field need not be long; if the electrons are numerous and closely packed, the rocket action will soon impart to the leaders all the velocity required to enable them to travel in a relatively weak field, and, in weaker fields, to pass forward a large amount of energy by means of successive relays of darts. Probably the most favorable place for the initiation of a powerful dart is a dense swarm of negative ions lying in a strong field; the field might be that between two swarms of oppositely charged ions. During thunderstorms, such swarms are scattered throughout the atmosphere, below the cloud, as well as in and above it, and conditions favorable to the initiation of a dart may well arise. The nascent trail of an ionizing radiation would be an especially favorable path for the initiation of a dart.

As here pictured, a lightning stroke has a definite direction, that of the advance of the electronic dart, and it involves three distinct phenomena: (1) Flying electrons ionize the air and produce certain characteristic effects where they strike. (2) Laggard electrons combine with the positive residues, giving rise to the flash. (3) A current results from the migration of the ions under the action of the field. This current may be very great, but it is merely an incident of the flight of the electronic dart, is subsequent to that, and, relatively to the dart, is exceedingly sluggish. Whatever its direction, the stroke is not a result of the cloud discharging to earth; the charge of the cloud does not pour into and along the flash, although ultimately the cloud does become partially discharged by the electrons or ions which have been freed by the dart. This discharge may involve relatively little motion of the charged particles initially resident in the cloud. Likewise, a side flash from a lightning conductor is not a result of the conductor discharging in that direction, but is the path of an electronic dart fired by the local field. The path ionized by the dart connects the lightning conductor conductively with the other terminus of the flash. If that terminus is earthed, some of the charge from the conductor may pass that way; if it is insulated, there will be merely a surge of charge into it and then back to the conductor, as the latter discharges along itself to earth.

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Successful Oil-electric Locomotive.—The Long Island Railroad has recently operated successfully a combination oil and electric locomotive. Description of the trial trip is given in a broadside issued by the General Electric Company from which the following data are taken:

A few days prior to its delivery to the Long Island Railroad, the 100-ton oil-electric locomotive completed the longest run ever made by a locomotive of this type hauling a loaded freight train. The run was made from the plant of the General Electric Company at Erie, Penna., to New York—a distance of 537 miles. No fuel or water was taken on during the trip; and the total cost of both fuel and lubricating oil for the 537 miles was only $26.15. The average fuel cost per locomotive-mile was 4.86 cents. The total kilowatt-hours generated was 3810, and the fuel cost per kilowatt-hour generated was .685 cent. The fuel cost per 1000 ton-miles was 12.90 cents.

The oil-electric locomotive is an internal-combustion oil engine which drives a generator, the current from which is applied to motors geared to the axles of the locomotive. The 100-ton locomotive which made the run from Erie to New York is about 46 feet long. The nominal rating of the traction motors at 600 volts is 200 h.p. each, or 800 h.p. for the four motors. The generator is operated by two 300-h.p. internal-combustion engines using low-grade fuel oil. The generator is of the direct-current, compound-wound, commutating-pole type, developing 600 volts. For test purposes, the oil engines were operated continuously during the trip from Erie to New York. An additional fuel saving could, of course, have been attained by shutting down the engines during long stops.

This locomotive was first publicly tried early in December of 1925 at the plant of the General Electric Company at Erie for the benefit of a visiting party of railroad officials, engineers, and transportation authorities. Starting from a standstill at the foot of a 1 per cent. grade, with a trailing load of 1315 tons, the locomotive accelerated up the grade to a speed of six miles per hour. Another test showed the oil-electric locomotive with two cylinders cut out of one of her engines, balanced perfectly between the motors. H. L.

A SINGLE STRAIGHT CONDUCTOR AS A NEW FUNDAMENTAL. REPLY TO A REJOINDER.

EDITOR,

JOURNAL OF THE FRANKLIN INSTITUTE,

SIR:

In your February issue, p. 245, Prof. Leigh Page claims to show, by calculations and an experiment, that certain results which I had published concerning the properties of the single conductor, were wrong.

Permit me to call attention to the very evident fact that his experiment and calculation both involve the *return conductor* as an *essential factor,* and therefore do not apply at all to the true single conductor, the very characteristic of which, according to such authorities as Maxwell, Northrup, Kennelly, and others, including probably Ampère, is that all other circuits, including of course its own return, are so far removed that their effects may be neglected. With a nearby return the energy per unit length is of course very much greater. CARL HERING.

PHILADELPHIA,
February 6, 1926.

Calcium Cyanide.—Calcium cyanide hitherto has been known only in solution. A process for its manufacture on a large scale is described by F. J. METZGER (*Ind. and Eng. Chem.*, 1926, **18**, 161–163). A vacuum crystallizer is used. Into it are introduced 900 pounds of pure liquid hydrocyanic acid containing about six pounds of water. The agitator is started; cold water is circulated through the jacket of the apparatus; and 300 pounds of finely ground calcium carbide are gradually introduced during a period of thirty to forty-five minutes. Acetylene is evolved, and calcium cyanide is produced. The entire reaction is completed in forty-five minutes to one hour after the initial introduction of the carbide. Warm water is then circulated through the jacket to evaporate any excess of hydrocyanic acid and to dry the product, which is then transferred to air-tight containers. The calcium cyanide, thus produced, contains from 52 to 58 per cent. of cyanogen, is soluble in water, dilute and absolute methyl alcohol and ethyl alcohol, and reacts with the atmospheric moisture to yield hydrocyanic acid. It has great value as an insecticide. J. S. H.

Physiological Action of Velvet Beans.—Velvet beans are used as a soil improver and forage crop. The acreage devoted to these beans was approximately 5,000,000 in 1917, and is now somewhat less than 3,000,000. Attempts have been made to introduce the beans themselves, and products manufactured from them, such as a meal, as food for man and as feedstuffs for domestic animals. The effect of ingestion of the cooked beans on man has been studied by EMERSON R. MILLER, O. N. MASSENGALE, and M. A. BARNES, of the Alabama Polytechnic Institute (*Jour. Am. Phar. Asso.*, 1925, 14, 1113–1114). Usually one and a half ounces or more of the velvet beans were ground, cooked by prolonged boiling in water, then eaten, They had an unpleasant taste, even when seasoning was added. They produced fulness and heaviness in the stomach, nausea, headache, irritation, restlessness, sleeplessness, and perspiration. One subject ate 70 grams, and suffered from sudden emesis seven hours later. These disagreeable effects are probably due to the presence of an amino acid related to pyrocatechin. A volatile substance is also present, it produces a violent headache in the temporal region and irritates the eyes. These results demonstrate that velvet beans are not a food for man. J. S. H.

Separation of Columbium and Tantalum.—GEORGE W. SEARS, of the University of Nevada (*Jour. Am. Chem. Soc.*, 1926, 48, 343–348), has devised a new method for the separation of the two rare elements, columbium and tantalum. He recommends the following procedure. Fuse one part of the ore with nine parts of sodium pyrosulphate at a temperature between 835° and 875° C. Cool. Leach with water for several hours to disintegrate the mass and remove it from the crucible. Filter the solution, and wash the residue with hot, approximately three normal hydrochloric acid, until free from iron. Treat the pure white residue in a beaker with a mixture of equal volumes of concentrated sulphuric acid and water. Cover with a watch glass, and heat the beaker on a sand bath until boiling ceases. Cool. Filter through an asbestos filter with the aid of suction, and wash the residue with cold six normal sulphuric acid until the washings no longer give a precipitate with ammonia water. The columbium is completely dissolved, while the tantalum remains in the residue.

Tantalates and columbates are probably formed during the fusion. J. S. H.

Melting-points of Alkaline Earths.—EARLE E. SCHUMACHER (*Jour. Am. Chem. Soc.*, 1926, 48, 396–405) has determined the melting-points of the monoxides of the metals of the alkaline earths with the following results: Calcium oxide, 2849° K.; barium oxide, 2196° K.; strontium oxide, 2703° K. J. S. H.

NELA RESEARCH LABORATORY NOTES.*

THREE BODY COLLISIONS IN AN IONIZED GAS.

By R. Rudy.

As Fowler and others have pointed out, if a steady state is to be reached in a gas which is ionized by light the reverse process must occur; that is, emission of light in the capture of an electron by an ion. Where ionization by collision occurs, the reverse process will establish a condition of equilibrium, that is, capture of an electron and transfer of the energy of recombination to a third electron which happens to be present. In a discharge tube this mechanism would produce fast electrons out of slow ones, that is, electrons which could travel against a higher negative potential than, for instance, the cathode fall. If all the electrons are supposed to have the same energy E_0 (in volts), the rate of production of ions per cm.^{3} and per second is

$$4 \times 10^{-6} r x_1 y \frac{1}{\sqrt{W}} \left(\frac{1}{E_0} - \frac{1}{W} \right)$$

the rate of destruction by capture

$$2.2 \times 10^{-27} q x_2 y^2 \cdot \frac{1}{W (W + E_0)^2}$$

(W being the energy necessary for ionization, r the number of electrons in the same group, q the weight of the normal orbit of the returning electron, approximately twice the inner quantum number; x_1, x_2, y concentration of atoms, ions and electrons.)

In order to obtain from three body collisions a measurable number of "over-speed" electrons, a few microamperes, for instance, y would have to be 10^{22} or more, whereas the electron concentration measured in discharge tubes is of the order of 10^{12} or less. In certain cases, however (as in the case of α-rays), y means the density of certain groups of valency electrons, and near the atom the density of the electrons is of the order required to give an appreciable number of high-speed electrons.

If the energy of the electrons is distributed according to

* Communicated by the Director.

Maxwell's law (temperature T), the rate of recombination becomes

$$1.2\,\frac{q}{E_0^3}\cdot 10^{-27}\cdot x_2 y^2\cdot \frac{E_0^2}{k^2T^2}\left[1+\frac{E_0}{kT}\cdot e^{\frac{E_0}{kT}}\,Ei\left(-\frac{E_0}{kT}\right)\right].$$

The rate of ionization is then

$$\frac{6.3.10^{-6}}{E_0^{3/2}}\cdot r\cdot x_1 y\left(\frac{E_0}{kT}\right)^{1/2} e^{-\frac{E_0}{kT}}\left[1+\frac{E_0}{kT}\cdot e^{\frac{E_0}{kT}}\,Ei\left(-\frac{E_0}{kT}\right)\right]$$

which gives the same result.

The equilibrium conditions lead to rather high values for the concentration of the positive or negative charges.

COLLECTOR CHARACTERISTICS IN NEON.

By R. Rudy.

A BEAM of electrons of 50 or 70 volts from a tungsten ribbon was sent through neon and received on a collector facing the cathode, the pressure of the gas varying from 0.006 to 0.1 mm. Hg and more. With the collector more negative than the cathode, the positive saturation current was obtained. When the collector was at the same potential as the cathode, a sharp break in the current occurred (the fastest electrons now being able to reach the disc) followed by a linear increase with voltage (as in Ohm's law) up to near the saturation current, the midpoint giving nearly the average energy of the electrons. As the collector was moved by steps of .5 cm., the positive-ion current remained almost constant for a distance of 2 or 3 cm.; however, the electron saturation current and at the same time the slope of the straight line decreased, all the electrons losing energy in passing through the gas. Reduced to the number of electrons received in the first position, this loss would be about 8 volts/cm. for 0.020 mm. Hg (10 volts/cm. for 0.30 mm., 12 volts/cm. for 0.048 mm.). The current due to primary electrons was 940 microamperes in the first position of the collector (near the anode), 770 in the second, 560 in the third, 420 in the fourth position, etc. The saturation value was less and less marked as the pressure was increased. At the same time the break near 0 volts due to the primary electrons disappeared; on account of increased ionization in the gas, the discharge current rose above the thermionic emission obtained from the filament. Changing the pressure produced the same variations as moving the collector farther away from the cathode.

The theory of the loss of energy of electrons in passing through a gas like neon gives for the distance, x, in which the velocity drops from V_0 to V

$$x = \frac{V_0^4 - V^4}{3nK_1} \cdot \frac{1}{z_0 - z} \int_z^{z_0} \frac{dz}{1nz} \text{ where } 1nz = \frac{4}{3}\left(1nV^2 - \frac{1}{r}\Sigma\nu + K_2\right).$$

In neon at .01 mm. pressure 100-volt electrons become 70-volt electrons after 3.1 cm., 60-volt electrons after 4.1 cm., 50-volt electrons after 5 cm. These are losses of the order of magnitude found in the experiments.

With increasing positive potential an intermediate group of electrons was collected, and then the Townsend ionization current was obtained.

With a suitable gas these changes are accompanied by variation in luminosity. When the collector potential is positive enough to allow electrons to excite resonance radiation, luminosity first appears near the collector and then farther and farther out in space, the lines of higher potential now showing up near the disc. Finally a complete negative glow may appear.

Most experiments were made with 5 milliamperes current and 70 volts. With over 10 milliamperes an electron current was observed when the collector was still highly negative, so that the electrons would have to have energy above the applied voltage. In the experiments as performed, however, a discontinuity in the collector current was always observed for the higher density of the ion current (or discharge current). The change was often irreversible, as is observed when the space charge breaks down as a result of ionization. The break was smaller the more nearly the positive-ion current was proportional to the discharge current.

Another entirely different type of collector characteristic was obtained at low pressures with 150-volt electrons. After having reached the saturation value, the current due to the primary electrons decreased strongly and increased again as the potential was raised.

The experiments are now being extended to He and Na; at the same time the influence of secondary electrons will be considered.

The Scattering of Light at Liquid Boundaries. C. V. RAMAN and L. A. RAMDAS, University of Calcutta. (*Proc. Roy. Soc.*, A749.)—In this paper it is transparent liquids that are examined.

A previous paper discussed the effect at the surface of mercury. When a beam of light is incident on the surface of a transparent liquid, there is scattering not only at the surface but also within the liquid. Fortunately it is possible to distinguish one from the other. A well-defined image of the sun having been formed on the surface of the liquid, the observer notes that its appearance changes as he changes his position, while this is not true of the internal scattering. The light from the surface is, further, far less blue than that from the interior. Moreover green, yellow and red filters held in front of the eye reduce the brightness of the surface opalescence less than that of the body of the liquid. The lighter paraffins which have low surface tension show surface opalescence distinctly, as did all the chlorides examined. "Carbon di-sulphide has an enormous internal-scattering (about fifty times that of pure water), and the surface-scattering can hardly be distinguished except for certain favorable directions of incidence and observation."

The authors discuss for ethyl-ether the changes in intensity and in polarization that occur as the direction of the incident beam and of the line of observation are varied. When the beam of light comes vertically downward upon the surface, surface-opalescence can scarcely at all be seen from above, but is well seen from below, the liquid half filling a sphere. "In the latter case, when viewed in a nearly vertical direction, the opalescent parch is quite distinct; as the eye is moved away to one side so as to view it more obliquely, there is no marked change in its intensity until the direction of observation is inclined to the vertical at an angle equal to the critical angle of the liquid, at which stage it suddenly brightens up. With further increase in the angle of observation there is a steady diminution in intensity until, for observation parallel to the liquid surface, the patch ceases to be visible." This is merely one of several unusual actions that have been observed. The connection between surface tension and surface scattering is thus expressed—"Other things being the same, a liquid having a higher surface-tension shows a smaller surface-opalescence and *vice versa*." Professor Raman's indefatigable industry in investigation, fine command of mathematical implements and perfect English diction show to western peoples not familiar with the Tamils what this race can accomplish in extending the frontiers of science. G. F. S.

Radiations and Malignancy.—According to DONALD C. A. BUTTS, of the Hahnemann Medical College (*Radiology*, 1926, 6, 47–54), the beneficial results in radium and X-ray treatment of malignant tissues are due to radiations of a negative nature which reduce the increased potential of neoplastic tissues. The caustic action of such rays is attributed to the presence of an excess of original or induced electrons in the tissues. If the quantities of electrons be equilibrated, neoplastic cells may be restored to a normal condition. J. S. H.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

PHOTOGRAPHIC SENSITIVITY: A COLLOID CHEMICAL PROBLEM.[1]

By S. E. Sheppard.

In a paper presented at the Colloid Symposium at Madison in 1923, the author discussed one important factor affecting photographic sensitivity. This is grain-size, or dispersity of the silver halide, and the distribution of grain-sizes in one and the same emulsion. It was shown then that in one and the same emulsion sensitivity increases statistically with the size of grain in the sense that the chance of a grain being made developable by a given exposure increases with the size (projective area). Other factors intervene, however, as between one emulsion and another, so that average grain-size is not the sole factor conditioning sensitivity.

It was found several years ago by Lüppo-Cramer that the sensitivity of plates could be greatly diminished by treatment before exposure with chromic acid, followed by thorough washing to remove the chromic acid. This desensitizing reaction has been quantitatively investigated in recent years both in England and in this country, and the results of the work are discussed in this paper. It is concluded that high photographic sensitivity is connected with something other than silver halide which is formed in the grains. Experiments by the author are described which show that emulsions made in the same manner, and having the same grain-size properties, can have quite different photographic sensitivities and properties according to the gelatin used. Hence, it is concluded that the substance in question is specifically afforded by the gelatin.

* Communicated by the Director.

[1] Communication No. 241 from the Research Laboratories of the Eastman Kodak Company, and published in the *Colloid Symposium Monograph*, 3: 76, 1925.

WASHING MOTION PICTURE FILM.[3]

By K. C. D. Hickman.

MOTION picture film loses hypo exponentially in a rapid stream of water. The actual rate of washing under practical conditions depends on three factors: The nature and degree of swelling of the emulsion; the rate of stirring of the water; and the rate of renewal of water in the washing vessel. Washing takes place most efficiently when the rate of diffusion from the film is equal to the rate of dilution in the vessel. As this requires that the water be changed every half minute such a condition is impracticable, and compromises effecting the same result must be substituted. Washing by " changes " or in " cascade " can be made to give rapid washing, especially if vigorous stirring is employed.

The nature of town water supplies, the effects of high temperatures, and partial washing in sea water is examined. The theoretical advice is reënforced in the practical recommendations.

Double Fluorides of Zirconium.—M. M. WINDSOR, of the University of Kentucky (*Jour. Am. Chem. Soc.*, 1926, **48**, 310–312), describes newly discovered double fluorides of zirconium with aniline, brucine, cinchonine, quinine, quinidine, and strychnine. J. S. H.

Fluorides of Aluminum.—MARTIN TOSTERUD (*Jour. Am. Chem. Soc.*, 1926, **48**, 1–5) has prepared aluminum fluoride in both the anhydrous and the hydrated form, as well as the double fluorides of aluminum with potassium and rubidium. Aluminum fluoride was prepared by solution of alumina in hydrofluoric acid in a Bakelite beaker. The crystalline, hydrated salt was obtained by chilling the solution of the fluoride. It was analyzed and found to have the formula $Al_2F_6.18H_2O$. This salt was placed in a platinum crucible, which was then heated in a bomb, under pressure in the presence of water. The anhydrous fluoride was obtained. The double fluorides were prepared by mixing solutions of aluminum fluoride and an alkaline fluoride, so that one molecular equivalent of the former and six molecular equivalents of the latter were present. A gelatinous precipitate formed. It and the supernatant liquid were heated under pressure in a closed system. Crystalline double fluorides deposited upon cooling to room temperature; they had the formulæ $4KF.Al_2F_6$ and $4RbF.Al_2F_6$, respectively. When the same procedure was used in an attempt to obtain a double fluoride of sodium and aluminum, the yield of crystals was insignificant. J. S. H.

[3] Communication No. 252 from the Research Laboratories of the Eastman Kodak Company, and published in *Trans. Soc. Mot. Pic. Eng.*, No. 23, 62, 1926.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

CHEMISTRY AND ANALYSIS OF THE PERMITTED COAL-TAR FOOD DYES.[1]

By J. A. Ambler, W. F. Clarke, O. L. Evenson, and H. Wales.

[ABSTRACT.]

BEFORE certifying any batch of a permitted coal-tar food dye as harmless, the Bureau of Chemistry must ascertain the exact composition of the color in question, as well as its purity. The chemical composition, physical properties, and certain important factors in the preparation, as well as the tolerance for impurities, of the eleven permitted coal-tar food dyes are given in Department Bulletin 1390. The methods of analysis used in the Bureau of Chemistry to determine their composition are discussed in detail.

Copies of the bulletin may be obtained on application to the Director of Information, Department of Agriculture, Washington, D. C.

FORMALDEHYDE IN CERTAIN MARINE PRODUCTS.[2]

By D. B. Dill and P. B. Clark.

U. S. Food and Drug Inspection Station, San Francisco, Calif.

[ABSTRACT.]

WHEN formaldehyde is found in a foodstuff it is usually considered to have been added as a preservative. Since the use of formaldehyde as a preservative is almost universally prohibited by law, its natural occurrence or development in a foodstuff is a matter of great interest.

Experiments conducted in the Bureau of Chemistry showed that formaldehyde develops in sterile canned crustacea and so-called red rock cod (Sebastodes sp.). The development of formaldehyde in these canned marine products is independent of the nature of the container and of the processes of can corrosion or

* Communicated by the Chief of the Bureau.

[1] Issued as U. S. Dept. Agr. Bul. 1390, March, 1926.

[2] Published in *J. Asso. Official Agr. Chemists*, 9 (Feb., 1926) : 117.

the blackening of these products from iron sulphide formation. It takes place in the absence of free oxygen.

Acidification and steam distillation failed to recover more than one-third of the formaldehyde added to formaldehyde-free salmon. A concentration of formaldehyde in canned crustacea as high as one part in 30,000 was sometimes found. Taking into account the failure to obtain complete recovery in distillation, it is possibly as high as one part in 10,000.

THE QUANTITATIVE DETERMINATION OF UNSAPONIFIABLE MATTER IN WHEAT FLOUR, ALIMENTARY PASTES, AND EGGS.[3]

By Raymond Hertwig and L. H. Bailey.

[ABSTRACT.]

IN CONNECTION with official food regulatory work it is sometimes important to know whether or not the usual method of direct ether extraction permits the quantitative determination of unsaponifiable matter. Consequently the Bureau of Chemistry undertook a comparative study to determine the unsaponifiable matter in extracts obtained by various methods of analysis from samples of flour, alimentary pastes, and eggs. Petroleum ether extract was not included with the others as it is generally recognized as being less efficient than ethyl ether. The unsaponifiable matter in the extracts was determined by the Kerr-Sorber method as modified by Hertwig and Jamieson.

The results obtained indicate that the direct ether extract of flour and eggs does not contain all the unsaponifiable matter of these materials. The hydrolysis of the sample with strong acid in the acid hydrolysis method for extraction of fat apparently has some chemical action on the unsaponifiable matter which causes low results for flour and eggs. The A. O. A. C. neutral method for the lipoid extraction of flour, alimentary paste, and eggs gives the highest results. This method is also believed to be the most satisfactory from the standpoint of operation for general purposes, and it is also, to all appearances, the most accurate quantitatively.

[3] Published in *J. Asso. Official Agr. Chemists*, 9 (Feb., 1926) : 122.

A TABULATION OF THE ALUMINUM SILICATE MINERALS.[4]

By Edgar T. Wherry.

[ABSTRACT.]

FOR the study of the formulas of minerals containing three essential components, two components may be plotted on coördinate paper. If a diagonal line is drawn to connect the two 100 per cent. points, the third component falls automatically, in reverse order, on a line joining the zero point with the centre of this diagonal. On applying this plan to the aluminum silicate minerals, placing the diagonal line up and down, for convenience, and assuming that the various ratios between Si and Al form a harmonic series, N_3, the following minerals are recognized to exist. Well-established species are underlined, and end-members are placed in parentheses:

Si : Al.	Colloids.	Meta-colloids.	Crystals.	Notes.
0 : 1	.....	(emery)	(corundum)	anhydrous.
0 : 1	(sporogelite)	(empholite)	(diasporite)	15% H_2O.
0 : 1	(cliachite)	(gibbsite)	(hydrargillite)	35% H_2O.
1 : 3	collyrite	mullite	mullite, crystd.	"artificial sillimanite."
1 : 2	allophane	fibrolite	sillimanite	also cyanite and andalusite.
2 : 3	samoite	.....	kochite	study needed.
1 : 1	halloysite	cryptotilite	kaolinite	possibly other meta-colloids.
3 : 2	steargillite	clay-gouge	anauxite	clay-gouge since termed beidellite.
2 : 1	cimolite	agalmatolite	pyrophyllite	montmorillonite contains magnesium.
3 : 1	termierite	malthacite	.....	study needed.
1 : 0	(opal)	(chalcedony)	(quartz)	also tridymite and cristobalite.

Composition of Soap Films. MARY E. LAING. (*Proc. Roy. Soc.*, A749.)—The soap was made from the purest obtainable materials, boiled-out conductivity water being used. About 150 c.c. of the solution was shaken in a glass separating funnel, containing only an atmosphere of pure nitrogen for the avoidance of chemical action on the films. After a period of two minutes for settling the

[4] Published in *American Mineralogist*, 10 (June, 1925) : 140.

100 c.c. of liquid which collects in that time, the "residue" is run off. Further liquid coming from collapse of the froth, the "intermediate solution," is similarly separated. The stiff foam is let stand over night and produces 25 c.c. of liquid. The specific conductivity of the original soap, the residue and the liquid from the foam were measured several times. The residue always had a smaller and the foam a larger conductivity than the original solution. The reduction on the average amounted to 2.2 per cent. and the increase to 2.5 per cent. Similarly the refractive index of the residue was smaller and that of the foam greater than that of the original solution. Chemical analysis showed that the foam contained, in comparison with the soap solution, 6.3 per cent. more sodium and 6.7 per cent. more fatty acid. In further analyses changes in chemical composition amounting to as much as 25 per cent. were detected. An acid sodium soap collects in the surface, and not oleic acid as such. The composition of the material in the surface is NaOleate.0.61HOleic.

G. F. S.

Airplanes in Insect-Pest Control.—(U. S. Department of Agriculture, Clip Sheet No. 398, February 8, 1926.)—The experimental work done by the Bureau of Entomology in the use of airplanes for distributing insecticides has been carried to the point where commercial organizations have now undertaken this operation as a business. Airplane dusting is a proved success in the control of cotton insects. During the cotton-growing season of 1925 more than 50,000 acres of cotton were dusted commercially with airplanes. Great progress has been made in the development of special planes for cotton dusting, the best methods of flying, and the application of the principles of airplane dusting to the operation of ordinary ground machinery.

At Montezuma, Ga., comparative tests have been made on large peach orchards with airplanes and ground power dusters. By means of the airplane dusters it was possible to apply the combined insecticidal and fungicidal dust very rapidly. About 5000 trees were dusted per hour, including the time required to return to the landing field and reload. The final results from airplane-dusted peach trees as compared with results from trees dusted with ground machines indicate practically as good control of the curculio by the one method as by the other.

Very successful tests have been made to determine the feasibility of airplane distribution of larvicides over large areas against malaria mosquitoes. Flooded rice fields where mosquitoes breed abundantly are well adapted to airplane treatment.

In making bark-beetle surveys on the Sierra National Forest airplanes were used to locate infested trees. An observer was carried in each plane and photographs were taken of nearly twenty square miles of timberland. A much clearer idea of the distribution of the infestation was obtained and the infested trees were readily located on the prints.

R.

NOTES FROM THE U. S. BUREAU OF MINES.*

FIRING OF REFRACTORY WARES.

By G. A. Bole and Others.

THE Bureau of Mines has brought to a close an investigation begun in 1923, of problems in firing refractories, that was undertaken at the urgent request of, and conducted in coöperation with, the Refractories Manufacturers' Association. The primary objects of the study were to increase the efficiency of burning conditions in the plants, and to obtain data on fundamental conditions of operation. The three principal objects with regard to each plant were production of better ware, saving of fuel, and increased kiln turnover.

The work was conducted by means of test runs at the plant, supplemented by laboratory tests in the laboratory car Holmes, and the ceramic station at Columbus, recently transferred to the Bureau of Standards. At most of the plants tested, the changes that were made by the bureau engineers in the operation of the kilns resulted in reducing the time of burning, 13 to 35 per cent., with an average of 19 per cent. At the same time, large savings in fuel were effected, in one plant as much as 43 per cent., the average being 13.5 per cent. for the plants tested, as compared with former practice. These economies were effected without any sacrifice in quality of ware; on the contrary, the quality was improved in many of the tests. Further details are given in a report in course of publication by the Bureau of Mines.

QUARRY PROBLEMS IN THE LIME INDUSTRY.

By Oliver Bowles.

LIME is a product of tremendous importance in modern industry, in agriculture as fertilizer, in building construction, and in numerous other industries. The annual production of limestone used in lime manufacture is between eight million and nine million tons. In 1922 the Bureau of Mines, at the request of the National Lime Association, began a study of limestone quarrying with the object of promoting more economical methods of operation, and utilization of waste material. In this work, recently completed,

* Communicated by the Director.

field studies were made at many quarries, supplemented by observations on lime practice. Much information has been obtained on methods of stripping, drilling, blasting, loading, and transportation. The results of the study will be published as a bulletin wherein the methods employed are compared and the best working principles shown, in order to assist lime manufacturers in improving their practice and in conducting quarrying on the most economical and efficient basis.

RATE OF COMBUSTION OF COAL-DUST PARTICLES.

By C. M. Bouton and J. H. Hayner.

WHILE large-scale tests by the Bureau of Mines and other agencies studying methods of preventing coal-mine explosions have shown that coal dust is explosible and that rock-dusting is a practical means of rendering coal dust inert, the exact nature of the mechanism of an explosion of coal dust and air is not known. The Bureau of Mines has recently completed a second series of experiments which has for its object the gathering of data that will be of direct aid in determining the exact nature of the propagation of a dust explosion. In the first series, a method of accurately sizing the fine coal dust for experiment was developed by floating the finer particles away from the coarser by means of gentle air-currents. In the present series, data were obtained on the relative inflammability of the different sizes thus obtained. The tests show that inflammability does not increase indefinitely as the particle size decreases, but approaches a maximum at a definite size and then falls off. Formerly, it had been generally accepted that explosibility of a dust increases with fineness. The data will be applied in further experiments being conducted along this line, and are being published more fully as a coöperative bulletin of the Carnegie Institute of Technology.

Native Copper.—The chemistry of the deposition of native copper from ascending solutions is discussed in great detail by ROGER C. WELLS (U. S. Geol. Survey Bull. 778, 71 pages, 1925). Four theories have been proposed to explain the deposition: Cooling, dilution, fractional oxidation of copper sulphide, and neutralization and reduction. In the application of these theories, the essential conditions of each ore district must be considered. Wells also reports the results of 165 original experiments on the deposition of copper.

J. S. H.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting Wednesday, March 17, 1926.)

THE stated monthly meeting of the Institute was called to order at eight-eighteen P.M. by President W. C. L. Eglin.

The President announced that the minutes of the February meeting had been printed in full in the March number of the JOURNAL and that the minutes would be approved as printed unless there were objection. No objection being offered, the minutes were declared approved.

The Secretary stated that since the last meeting, eleven new members of the Institute had been elected.

The Secretary also read notices of the deaths of two conspicuous members of the Institute:

William H. Thorne, Director of the Drawing School of the Institute from 1881 to 1916; author of the first text-book published on Mechanical Drawing; member of the Committee on Science and the Arts for fifty years. (This fact would have been appropriately celebrated by the Committee if Mr. Thorne had remained in health for two weeks more.)

Dr. H. Kamerlingh Onnes, Director of the Physical Laboratory, University of Leiden, Holland; honorary member of The Franklin Institute; awarded the Franklin Medal in 1915 "in recognition of his long-continued and indefatigible labors in low-temperature research." His last contribution to scientific literature will be published in the April number of the JOURNAL of the Institute.

Expression of sincere regret for the deaths of these two members was made.

The President of the Institute expressed his personal regret at the death of Mr. Thorne and mentioned the fact that many successful men in industry in Philadelphia owed much of their success to the training which they had received under Mr. Thorne.

There being no further business, the President introduced as the lecturer of the evening, Colonel E. Lester Jones, Director of the U. S. Coast and Geodetic Survey. Colonel Jones spoke on "Science and the Earthquake Peril." His lecture was an exceedingly instructive one. He spoke of the occurrence of earthquakes, and of the scientific possibilities of forestalling damage by such cataclysms.

The President of the Institute adjourned the meeting with an expression of sincere appreciation for Colonel Jones' most interesting talk, at nine-fifty-seven P.M.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, March 3, 1926.)

HALL OF THE COMMITTEE,
PHILADELPHIA, March 3, 1926.

MR. CLARENCE A. HALL *in the Chair.*

The following reports were presented for final action:

No. 2842: Work of Dr. Charles S. Hastings.

This report, recommending the award of the Elliott Cresson Medal to Dr. Charles S. Hastings, Professor Emeritus of Yale University, "in consideration of his scientific attainments and of his originality and skill in the design and computation of optical systems of the highest order and in recognition of his life work as a man of science who sought not the light for his own illuminating," was adopted.

No. 2849 and No. 2850 } Literature.

It was unanimously decided that two Louis Edward Levy Medals be awarded—one to Prof. E. G. Coker, of London, England, for his paper on "Photo-elasticity" appearing in the March, 1925, issue of the JOURNAL, and the other to Mr. F. W. Peek, Jr., of the General Electric Company, Pittsfield, Mass., for his paper on "Lightning" appearing in the February, 1925, issue of the JOURNAL.

The following report was presented for first reading:

No. 2843: Akeley Moving Picture Camera.

The following minute on the death of Mr. William H. Thorne was unanimously adopted:

"In the death of Mr. William H. Thorne, The Franklin Institute has lost a faithful member and one who has for many years rendered an unstinted service.

"Mr. Thorne became a member of the Committee on Science and the Arts on March 1, 1876, and this meeting would have been the fiftieth anniversary of his membership.

"In 1881 he became Director of the Drawing School of The Franklin Institute. In 1883 he wrote a Junior Course in Mechanical Drawing and within the following two years published the Intermediate and Senior Courses on the same subject. These were the first text-books in mechanical drawing published in the United States and although designed primarily for the school of the Institute, they were adopted by many technical schools throughout the country. The United States Military Academy at West Point not only used these books, but had constructed under Mr. Thorne's supervision a model of the engine shown in the Senior text-book. Mr. Thorne became director emeritus in 1916.

"As indicative of his interest in the work of the Institute it should be noted that of the fifty-eight meetings of the Committee on Science and the Arts held since January 1, 1920, he attended forty-four—a record of attendance of 76 per cent.

"It is with deep regret that the Committee on Science and the Arts has learned of his death and hereby records its sympathy with his family in its bereavement.

"*Resolved*, That this report be spread upon the minutes of the Committee and that a copy be sent to Mr. Thorne's family."

GEORGE A. HOADLEY,
Secretary to Committee.

BARTOL RESEARCH FOUNDATION.

FOUNDATION LECTURES BY DR. L. W. McKEEHAN.

A SERIES of three lectures will be delivered on the afternoons of April thirteenth and April sixteenth, and on the evening of April twenty-first, by Dr. L. W. McKeehan, of the Bell Telephone Laboratories, Inc., New York City, in the Lecture Hall of The Franklin Institute.

These lectures will be open to the members of the Institute and to those especially invited to attend. Requests for cards of admission should be addressed to—The Secretary, The Franklin Institute, 15 South Seventh Street, Philadelphia, Penna.

Synopses of the lectures are given herewith.

Tuesday, April 13th, 4 o'clock P.M. "Magnetostriction in Iron, Nickel and Cobalt."

Classical experiments on change in dimensions with change in magnetization, and on change in magnetization with forcible change in dimensions. Later experiments on pure metals. The theory of continuous media. The theory of manœuvre. Experiments on single crystals of iron.

Friday, April 16th, 4 o'clock P.M. "Magnetostriction in Alloys and Compounds."

Experiments on single crystals of magnetite. Experiments on alloys, particularly on those of iron and nickel. Recent experiments on permalloys. The theory of atomic magnetostriction. Change in electrical resistance with magnetization and with mechanical stress.

Wednesday, April 21st, 8.15 o'clock P.M. "Magnetostriction in Non-uniform Bodies."

Experiments on bodies chemically non-uniform. The preparation and behavior of bodies physically non-uniform. Internal strains. Annealing and quenching. Cold work. Studies of crystal orientation and of its effect on magnetization.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, March 10, 1926.)

RESIDENT.

DR. CHARLES B. BAZZONI, Professor of Experimental Physics, Randal Morgan Laboratory, University of Pennsylvania, Philadelphia, Penna.

MR. MAURICE C. BURTON, Retired Lumber Manufacturer, Wood-Norton Apartments, Germantown, Philadelphia. For Mailing: In care of Mr. Edward F. Henson, Lafayette Building, Philadelphia, Penna.

MR. HENRY C. EVANS, Student, Riverton, N. J. For Mailing: Haverford College, Haverford, Penna.

MR. PAUL QUINNELL CARD, Instructor in Chemistry, Woodbury, N. J. For Mailing: 45 Delaware Street, Woodbury, N. J.

MR. HARRY H. KELLER, Engineer, Jenkintown, Penna.

MR. GEORGE W. PERKINS, Instructor in Chemistry, Union Avenue, Delanco, N. J.

MR. H. L. RANDALL, President, Riverside Metal Company, Riverside, N. J. For Mailing: 709 Linden Street, Riverton, N. J.

MR. CHARLES H. SCHLACKS, President, Keystone Watch Case Company, Riverside, N. J. For Mailing: Bryn Mawr, Penna.

DR. HARRY M. SHARP, Physicist, Radiological Laboratory, General Hospital, Philadelphia, Penna. For Mailing: 5232 Chester Avenue, Philadelphia, Penna.

MR. EDWARD S. WOOD, JR., Student, Haverford College, Haverford, Penna. For Mailing: Riverton, N. J.

NON-RESIDENT.

DR. STEVENSON A. WILLIAMS, Lawyer, Bel Air, Md.

CHANGES OF ADDRESS.

MR. A. W. BERRESFORD, In care of Nizer Corporation, 7424 Mackie Street, Detroit, Mich.

MR. GEORGE BREED, University Club, 1510 Walnut Street, Philadelphia, Penna.

MR. J. C. DACOSTA, 3RD, Indemnity Insurance Company of America, 232 Walnut Street, Philadelphia, Penna.

MR. L. J. R. HOLST, 26 Haward Road, Brookline, Upper Darby P. O., Penna.

MR. EDGAR B. NICHOLS, 524 Wellington Avenue, Rochester, N. Y.

MR. L. R. RICKETTS, 325 Pacific Southwest Bank Building, Pasadena, Calif.

MR. SAMUEL SPITZ, 2100 South Bronson Street, Los Angeles, Calif.

MR. ALFRED O. TATE, 45 Sceptre House, 169–173 Regent Street, London, W 1, England.

MR. STEPHEN VAN DER LINGEN, Erinville, Hilton Road, Seapoint, Capetown, Africa.

MR. J. M. WEISS, 503 East Forty-first Street, New York City, N. Y.

NECROLOGY.

Mr. William H. Thorne, Philadelphia, Penna.

Dr. H. Kamerlingh Onnes, Director, Physical Laboratory, Leiden, Holland.

LIBRARY NOTES.

RECENT ADDITIONS.

BARNARD, J. E., and WELCH, FRANK V.—Practical Photo-micrography. Second edition. 1925.

CAILLER, CHARLES.—Introduction Géométrique à la Mécanique Rationelle. 1924.

Engineering Foundation.—Popular Research Narratives. Vol. 2. 1926.

Helmholtz's Treatise on Physiological Optics. Translated from the third German edition. Edited by J. P. C. Southall. Vol. 3. 1925.

HEYL, PAUL R.—The Common Sense of the Theory of Relativity. 1924.

HEYL, PAUL R.—The Fundamental Concepts of Physics in the Light of Modern Discovery. 1926.

Joint Committee on Civil Aviation of the United States Department of Commerce and the American Engineering Council. Civil Aviation; a Report. First edition. 1926.

NIELSEN, NIELS.—Tables Numériques des Équations de Lagrange. 1925.

PAINTON, EDGAR T.—Mechanical Design of Overhead Electrical Transmission Lines. 1925.

RICHTER, M. M.—Lexicon der Kohlenstoff-Verbindungen. Third edition. Four volumes. 1910–1912.

BOOK REVIEWS.

PRACTICAL PHOTO-MICROGRAPHY. By J. E. Barnard, F.R.S., and Frank V. Welch. xii–316 pages, 86 illustrations in the text and 15 plates, 8vo. New York, Longmans, Green and Company, 1925. Price, $6.

Books on the microscope and on photomicrography are rather numerous and range from small volumes, little more than pamphlets, to octavos. As a rule, they have seemed to the reviewer to be somewhat unsatisfactory, not giving enough detailed information. The application of photography to the microscope is one of the most important developments of modern science. The microscope is a most valuable instrument of research and photography enables permanent records to be made. Very interesting and valuable results have been obtained of late by the operation of the motion picture camera with the microscope. Color photography has also found valuable use. The striking phenomena exhibited by rock sections under polarized light can be very accurately and vividly reproduced and made permanent. In fact, this application of color photography seems to be one of the most satisfactory of its uses, for in most cases the colors obtained are rather garish and in working with polarized light no artistic effect is expected.

The work in hand is a very comprehensive presentation of the subject, including considerable information upon theoretical questions and a large amount of description of methods. It is liberally illustrated, though, as might be expected, many of the blocks are taken from catalogues. A wide variety of subjects is shown on the fifteen well-executed plates.

It is too strictly European in selection of topics to please entirely the American student. American work seems to be ignored. Silverman's illuminator, which is undoubtedly the best form for work with opaque objects under low power, is apparently not mentioned, although fair space is given to the problem of the opaque. The Bausch and Lomb apparatus for both vertical and horizontal arrangement is also not listed. It is strange that no mention is made in any of the manuals on this subject of the advantage of operating apparatus in the dark room. The reviewer has used this method for many years. It dispenses with the dark slide and thus eliminates the danger of disturbing the apparatus in drawing the shutter. A very simple and inexpensive attachment may be used, as was described not long ago by the reviewer in the *Amer. Jour.*

Pharm. This consists of a box about 25 centimetres long and of length and breadth to permit of the size of plate used. The apparatus as used takes a 3¼ × 4¼ plate. Supports at each short side of the box hold the ground glass and the sensitive plate which takes its place after the focus is adjusted. The box is carried on the draw tube by a snugly fitting opening. The apparatus is used vertically. It is to be noted, by the way, that in the section on illumination no mention is made of the condensed tungsten spiral lamps now available. The only incandescent bulb lamp mentioned in any detail is the pointolite. This is probably the best form, but its cost is a serious matter and for moderate powers as used for common animal and vegetable forms and rock sections, the cheaper lamps serve well.

It is gratifying to note that the metric system is generally used in the book and is specifically and emphatically endorsed. HENRY LEFFMANN.

INTRODUCTION GÉOMÉTRIQUE A LA MÉCANIQUE RATIONELLE. Par Charles Cailler, Professeur a l'Université de Genève. Ouvrage publié par H. Fehr et R. Wavre, Professeurs a l'Université de Genève. xii–627 pages, 6 × 9 inches, paper, 120 figures. Genève, Georg et Cie.; Paris, Gauthier-Villars et Cie., 1924. Price, 60 francs.

Since the days of the celebrated early writers of modern times on analytical mechanics, it has been the aim in formal treatises to present the subject in the most generalized form possible. The *Mécanique Analytique* of Legrange, published in 1788, is a notable example of this generalization. Its celebrated author in referring to it said: "Not a single figure will be found in this work." The present author, whose work is edited posthumously, if he has not deprived the reader of the aid and comfort of diagrams, has indeed adhered to the traditions of his illustrious predecessors in presenting the *Introduction Geometrique* in ultra-generalized terms. He says: "We do not limit ourselves to space of two or three dimensions, neither do we suppose that this space, which may be of any kind, is euclidean: It suffices that movement without deformation is possible."

The first part of the work deals with the algebraic theory of multilineal, quadratic forms and linear substitutions. The second part is devoted to elementary vectorial geometry, then to the theory of dynames of E. Study in which he introduces the complex coördinates of a straight line first introduced by Clifford. The third part deals with finite motion in which is included a chapter on quarternions. The fourth and final division applies to the consideration of infinitesimal movement which is treated with the same high order of generalization as the preceding sections. The section ends with a miscellaneous collection of applications to familiar mechanical movements. The section-headings are as follows: Part I—Algebraic study of geometry and kinematics in space of n-dimensions. Part II—Vectorial geometry; theory of dynames. directed geometry. Part III—Kinematics, a study of finite motions. Part IV—Kinematics, a study of infinitesimal movements.

The applications are somewhat disappointing in that they may be found satisfactorily analyzed in treatises in which the more commonly employed

mathematical methods are applied. Examples which illustrate the value of the methods used in dealing with questions beyond the reach of commonplace methods would do much to demonstrate the by-no-means-obvious value of the methods employed in this profound treatise. LUCIEN E. PICOLET.

GÉOMÉTRIE DU COMPAS. Par A. Quemper de Lanascol, Licencié ès Sciences avec une préface de M. Raoul Bricard, Ingénieur des Manufactures de l'État, Professeur au Conservatoire National des Arts et Métiers et a l'École Centrale des Arts et Manufactures. xx–406 pages, 5½ × 9 inches, with 288 figures, paper. Paris, Librairie Scientifique, Albert Blanchard, 1925. Price, 25 francs.

An unrestricted use of the compass and the ruler is the permissible means for the construction of problems and the demonstration of theorems postulated in the geometry of Euclid. Geometrically speaking, both the straight line and the circle are figures of definition and a figure composed of these elements is merely a visual aid in proceeding to the demonstration of a theorem based upon their properties. With regard to construction problems the ruler is apparently an equally fundamental device with the compass, but actually the ruler produces a copy only, more or less perfect, of a straight line while the compass traces an original and fundamental figure. The only direct method of tracing a straight line is by the Peaucellier linkage, the motions of whose elements are truly circular. The circle is *par excellence,* therefore the fundamental figure of geometry. There is moreover sometimes a decided draftsmanship advantage in effecting a construction with the compass alone, so that only the required straight lines of the final figure need be drawn.

Compass geometry, in which constructions are composed wholly of circles, and straight lines are represented by two of their points, is by no means a new method. The celebrated work "Geometria del Compasso," by Lorenzo Mascheroni dell'Olmo, was published in Pavia late in the eighteenth century and appears to have remained the only important work of the kind until recent times. The present author has drawn freely from this work and has consulted many other sources, but as stated by Professor Bricard, not less than one-half of Books I and II are his own contribution, and most of Book III on the applications of inversion.

The "compass-geometry" consists of a series of geometrical problems progressively arranged in three books, of which the first deals with usual fundamental problems of geometry, bisecting lines, bisecting arcs, intersection of lines, dividing lines, etc. This brief list conveys the impression of a commonplace collection and doubtless it would be if the straight line were employed in the constructions, but since only circles are permissible the constructions are markedly different from those of conventional geometry. Thus, in the simple problem of bisecting a line between two points A and B, seven circles are required, of which five have a radius, AB. The middle point C of the line is at the intersection of the remaining two of these circles of longer radius. Then there are constructions for finding fourth proportionals, mean proportionals, extreme and mean ratio, for the roots of a quadratic equation, and a number of other problems, all solved by the use of circles only.

A considerable amount of space is given the division of lengths and the

circumference. The methods of the division of lines are of interest more for their geometrical elegance than for their applicability. Methods of rectification of the circle, given in a later chapter, have more general application in practice. The compass method applied to the widely-used method of rectification of Rankine would be of unusual interest. The more modern aspects of geometry are represented in dealing with inscribed and escribed circles of a triangle, orthocentre, similitude and lastly in Book III, the construction of inverse figures, the principle employed in the Peaucellier link motion alluded to above and other mechanisms which trace inverse curves.

There is an immense amount of material in the book and the geometrical devotee who secures a copy is assured of many pleasant and profitable hours.

LUCIEN E. PICOLET.

MECHANICAL DESIGN OF OVERHEAD ELECTRICAL TRANSMISSION LINES. By Edgar T. Painton, B.Sc. Hons. (Lond.), A.M.I.E.E. vii–274 pages, 8¼ × 5½ inches, cloth, with 189 figures in line and half-tone. New York, D. Van Nostrand Company, 1925. Price, $6.

The major structural problems of an electrical transmission line project are in general within the province of the civil engineer. The poles or towers, as the case may be, which support the line are both specialties of that branch of engineering. The principles involved are old but in the practice and development of the art more ample and more precise data become available and more expeditious methods of deriving desired results from them are evolved. Literature dealing with the electrical elements of the line is very ample, but usually the constructional elements are dealt with in such works as a subsidiary subject less amplified than its importance warrants.

The work at hand is devoted exclusively to the structural elements of the line and has been written primarily for the designer and the consulting engineer. The author has, however, duly considered the requirements of the contractor and the operator by stressing at considerable length important details of construction and in including much useful information adapted to their particular needs. The eight chapters of the book form an excellently balanced collection of fundamental data and deductive results. The first deals with conductors, their materials, construction and mechanical properties. Particular attention is given to steel-cored copper conductors and stranded conductors in their various combinations. The second chapter contains a lucid account of sag and stress problems. Applicable formulas are derived from true catenary equations. Two graphic charts are described, one the Blondel chart which is based upon a parabolic equation, the other the Thomas chart from the *Transactions of the American Institute of Electrical Engineers* in which the values are derived from formulas in hyperbolic functions. Supports occupy the third chapter. Here the general lay-out of the line, loadings, spacing and type of support are considered. Among other valuable matter is a description of the sag templet and an explanation of its use. A fourth chapter is devoted to insulators and fifth and sixth chapters embrace, respectively, detailed accounts of wood and steel supports. In the seventh chapter miscellaneous constructional details are considered. Chapter eight covers methods of erection and their application. An appendix considers the determination of the deflections of

flexible supports due to unbalanced loadings such as may, for instance, occur from conductor breakage.

For use in this country, some objection may be made that the work represents British practice. It doubtless does so in the main, but the numerous references to American sources of information, as well as the soundness of its deductive matter, should bespeak for it a valuable sphere of usefulness in this part of the world. The work constitutes a highly satisfactory collection of theoretical information and material data presented in excellent typographical form.

LUCIEN E. PIOLET.

HELMHOLTZ'S TREATISE ON PHYSIOLOGICAL OPTICS. Translated from the third German edition, with appendices. Edited by James P. C. Southall, Columbia University. Vol. 3, The Perception of Vision. x–736 pages, numerous illustrations and 6 full-page plates, 8vo. Published by the Optical Society of America, 1925. Price, $7.

The general character of this great work has been set forth in the reviews of previous volumes. This is the closing volume. The text has been translated from the German and the editor has been assisted by a number of specialists. It is the largest volume of the series and is crowded with information upon the subject of vision. The text with some small exceptions is wholly from the German. Owing to the metaphysical nature of many of the questions that arise in the presentation of the subject, the editor has found the translation far more difficult than that of other portions of the work, but we may be sure that his rendering is trustworthy and in good English. The German of the profound professors who use that language is by no means always as clear as could be wished, and we are not astonished that the translator has met with serious difficulties, but we may feel sure that the essential meaning of all portions of the text will be found in this translation. The volume is sumptuously printed and as the final one of a work of unquestioned excellence, it will be welcome to all interested in the field to which it is devoted.

HENRY LEFFMANN.

METAL SPRAYING. The origin, development and applications of the metal-spray process of metallization. By T. Henry Turner, M.Sc., Lecturer in Metallurgy, the University of Birmingham, and N. F. Budgen, M.Sc., Ph.D., author of "Cadmium: Its Metallurgy, Properties and Uses." xiv–175 pages, 9 × 6 inches, cloth, with 165 figures. London, Charles Griffin and Company; Philadelphia, J. B. Lippincott Company, 1926. Price, $6.50.

Compared with other processes of applying protective and ornamental metal coatings, metal spraying is a relatively recent development. Apart from its other merits, it possesses the important advantage of applicability to finished objects *in situ*. In fact, its method of application is not unlike that employed in spraying paint upon finished structures. The apparatus which is employed for that purpose is aptly called by its inventor, Dr. M. U. Schoop, of Zurich, "a spraying pistol," for it seems it was the effect of the impact of a small-calibre bullet upon a metal target that suggested the method.

The authors, by availing themselves of the extensive collection of monographs on the subject which have appeared from time to time in periodical

publications to which they have added their own investigations, have produced a highly informative account of the early experiments, the development and the practice of metal spraying. The chapter headings are as follows: Early attempts at metal spraying, Development of the wire-spraying process, Modern metal-spraying apparatus and its operation, Efficiency of the process, Nature of sprayed metal, Comparison of the metal-spray process with other methods of metallization, Applications of the metal-spray process.

This, it seems, is the only book on the process which has appeared in English, and it is a notable addition to the literature of a highly ingenious and successful method of the important art of applying metal coatings. The make-up of the volume is in harmony with the usual fine quality of the Griffin-Lippincott products.

LUCIEN E. PICOLET.

THE FUNDAMENTAL CONCEPTS OF PHYSICS IN THE LIGHT OF MODERN DISCOVERY. Three Lectures at the Carnegie Institute of Technology, Pittsburgh, January, 1925, by Paul R. Heyl, Ph.D. 112 pages, 12mo. Baltimore, The Williams and Wilkins Company, 1926. Price, $2.

From the reading of this book the reviewer comes with a most pleasant feeling of having been led to heights from which the steady progress of physics lay revealed and yet of needing not at all to exert himself, so alluring was the upward way made by the literary skill of the author. When Doctor Heyl was a teacher in the Central High School of Philadelphia he collected a treasure of illustrations that must have made his classes highly interesting to his pupils. He has the art of illuminating a recondite statement by a happy parallel, as when, after discussing the transformation of all energy into heat at uniform temperature, he says, "Translated into the jargon of the physicist 'Götterdämmerung' means: 'The entropy of the universe tends to a maximum, and its available energy to a minimum.'" It is too often true that scientific writings are bald in style and involved in construction. Would that there were more physicists who, like R. W. Wood, could write deeply wise nonsense verses or who, like Maxwell, could use poetry to describe impact or the functioning of a galvanometer. In the book before us there is a blending of clarity and literary finish with a wide acquaintance with the development of physics.

After a foreword there are three chapters, each discussing a century. The eighteenth century is called by the author, "The Century of Materialism." "The natural philosophers of that day studied matter only. The modern concept of energy was not recognized. Forces were indeed known, gravitational, mechanical, electrical, magnetic, but all were regarded as properties of matter." "So strong was the tendency of the times to give materialistic explanations that the phenomena of heat, light, electricity and magnetism were explained by introducing the concept of imponderable kinds of matter," such as caloric, magnetic and electric fluids and corpuscles of light. Still another characteristic of the same century was "a failure to lay emphasis upon the quantitative where it might naturally have been expected." An instance of this is the case of the phlogiston theory of combustion held by Priestley, Cavendish, Black and Scheele. Here a simple application of quantitative reasoning would have cleared the road for the coming of a better theory. "This century bequeathed to that which succeeded it a rich inheritance of fact, a double

handful of isolated and distinct physical concepts, a half dozen different kinds of matter, ponderable or imponderable, and merely a beginning of law, order and correlation."

The nineteenth century, the century of correlation, took this legacy, worked it over and augmented it. It reduced the fundamental concepts of physics to two, matter and energy. In showing how this was done the author betrays his acquaintance with the discussions that took place when new discoveries had been made. The records of such discussions are often rich in suggestions that are valuable even at the present time. A new fact or a theory that must maintain itself against rivals already well established is far less intolerant of opposition than it is later. We become timid about questioning what all accept, and we ask only the scientifically conventional questions. Who nowadays would venture to ask himself, as did Faraday, whether all kinds of electricity are alike in all effects? One of those early and venturesome questions inquired whether invisible light waves travelled with the same speed as the visible waves. It is only by the application of textual criticism that one may learn that it was Doctor Heyl himself who answered this interrogation in the affirmative as a result of his experiments on the light of the variable star, Algol, and received a part of the Boyden award from The Franklin Institute.

Heat and work were correlated and the new concept, energy, was introduced by the work of Rumford, Carnot, Mayer and Joule. Electricity was connected with magnetism by Oersted, Faraday and Seebeck. Maxwell, by his prophetic theory, showed the bond between light and electricity, which Hertz subsequently verified by experiment. The term, entropy, is introduced as a poetical conception, although it be defined mathematically. "There may be such a thing as poetry under an integral sign, incongruous as the association may appear." There follows a discussion of the second law of thermodynamics with the possibility of evading it by the employment of Maxwell's demons. Reference is made to Svedberg's very interesting observations on the change of the number of colloidal particles in a given volume with the passage of time. The reviewer has been turned to the Swedish investigator's own book and cannot refrain from quoting from his results. In a certain volume the number of particles seen varied from 0 to 7. The average time during which none were visible was 2.57 seconds; this duration fell to 1.89 seconds for four particles. The average time from the presence of no particles in the space to the next instant when none were there was 9.35 seconds. For four particles this interval was 28.6 seconds and for seven it was 28 minutes. Similarly for 17 particles the interval between the appearances of so many would be 50,000 years. "An analogous calculation shows that a pressure difference of 1 per cent. between the two halves of 1 c.c. of a gas at ordinary conditions would on the average just appear each $10^{3\times10^{8}}$ years."

The twentieth century, the century of hope, during its first quarter has already contributed three theories of the first importance, the electrical theory of matter, the quantum theory and the theory of relativity. These are well discussed and some of the recent speculations are set forth in a pellucid way. In comparing two of the three theories mentioned the author says, "The relativity concept is already beginning to show its weakness, and, in the opinion of some of its leading exponents, is beginning to reach a barren stage; while

the concept of the quantum, though older than the relativity concept, is still fertile and vigorous."

The reviewer has noticed not a single error either in spelling of names or in fact. The book is good to read both from its make-up by the printer and from the manner in which it lies open before one.

When John Tyndall in the 70's of last century established his fellowships in the United States, he made possible such books as this, which comes from the pen of a former Tyndall fellow of the University of Pennsylvania

GEORGE F. STRADLING.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 227, The Variable Density Wind-tunnel of the National Advisory Committee for Aeronautics. By Max M. Munk and Elton W. Miller. 18 pages, illustrations, quarto. Washington, Government Printing Office, 1926. Price, ten cents.

This report contains an exact description of the new wind-tunnel of the Committee. It is the first American type wind-tunnel and differs from ordinary wind-tunnels by being surrounded by a strong steel shell, 35 feet long and 15 feet in diameter. A compressor system is provided to fill the entire wind-tunnel with air compressed to a density up to twenty-five times the ordinary atmospheric density.

It is demonstrated in the report that the increase of the air density makes up for a corresponding decrease in the scale of the model. Hence such American type wind-tunnel is free from scale effect.

The report is illustrated by many drawings and photographs. All construction details are described, and many dimensions given.

The method of conducting tests is also described and some preliminary results are given in the report. So far, the tests have confirmed the chief feature of this wind-tunnel—absence of scale effect.

Report No. 219, Some Aspects of the Comparison of Model and Full-scale Tests. By D. W. Taylor. 23 pages, illustrations, quarto. Washington, Government Printing Office, 1926. Price, ten cents.

This paper was presented before the Royal Aeronautical Society as the 1925 Wilbur Wright Memorial Lecture. It treats the subject of scale effect from the standpoint of the engineer rather than the physicist, in that it shows what compromises are necessary to secure satisfactory engineering model test data and how these test data compare with full-scale or with theoretical values. The paper consists essentially of three parts: (1) A brief exposition of the theory of dynamic similarity; (2) application of the theory to airplane model tests, illustrated by test data on airfoils from the National Advisory Committee for Aeronautics' variable-density wind-tunnel, and (3) application of the theory to propeller testing, illustrated by comparisons of model and full-scale results.

PUBLICATIONS RECEIVED.

Popular Research Narratives. Vol. II. Fifty brief stories of research, invention or discovery, directly from the "men who did it," pithily told in language for laymen, young and old. Collected by the Engineering Foundation.

174 pages, portraits, 12mo. Baltimore, The Williams and Wilkins Company, 1926.

Carnegie Institution of Washington. Researches of the Department of Terrestrial Magnetism. Vol. V, Ocean Magnetic and Electric Observations, 1915–1921. Magnetic results by J. P. Ault, Atmospheric electric results by J. P. Ault and S. J. Mauchly. Special reports. 430 pages, illustrations, plates, maps, quarto. Washington, Carnegie Institution of Washington, 1926.

Metal Spraying. The Origin, Development, and Applications of the Metal-spray Process of Metallization, by T. Henry Turner, M.Sc., and N. F. Budgen, M.Sc., Ph.D. 175 pages, illustrations, 8vo. London, Charles Griffin and Company; Philadelphia, J. B. Lippincott Company, 1926. Price, $6.50.

Aeronautics. Tenth Annual Report of the National Advisory Committee for Aeronautics 1924, including Technical Reports Nos. 186 to 209. 499 pages, illustrations, quarto. Washington, Government Printing Office, 1925. Price, $1.35.

Introductory Thermodynamics for Engineers, by Edward Bennett, E.E., and Harold Marion Crothers, Ph.D. 665 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, 1926. Price, $4.50.

Éléments d'Astrophysique. Introduction a l'étude de l'énergétique solaire et stellaire, par Albert Nodon, Dr. es. Sciences. 244 pages, illustrations, 8vo. Paris, Albert Blanchard, 1926. Price, twenty francs.

Géométrie du Compas, par A. Quemper de Lanascol, avec une préface de M. Raoul Bricard. 406 pages, illustrations, 8vo. Paris, Albert Blanchard, 1925. Price, twenty-five francs.

Mécanique Analytique des Théorie des Quanta, par G. Juvet, Professeur a l'Université de Neuchatel. 153 pages, 8vo. Paris, Albert Blanchard, 1926. Price, twenty francs.

Les Nouveaux Axiomes de l'Électronique (Mécanique des Électrons), par R. Ferrier, Ingenieur des Ponts et Chaussées. 63 pages, illustrations, 8vo. Paris, Albert Blanchard, 1925. Price, three francs.

Pression de la Lumière, par Pierre Lebedef. Traduit du Russe par T. Konsmine. 71 pages, illustrations, 8vo. Paris, Albert Blanchard, 1926. Price, seven francs, 50 centimes.

Il Volo Transpolare. Col. Ing. Umberto Nobile, Direttore dello Habilimento di Costruzioni Aeronautiche in Roma. 27 pages, illustrations, maps, 8vo. Estratto dagli "Annali dei Lavori Pubblici," Anno 1925, fasc. 11. Roma, 1925.

U. S. Bureau of Standards: Scientific Papers, No. 518, Metallographic Etching Reagents III: For Alloy Steels, by Edward C. Groesbeck. 59 pages, illustrations, 8vo. Washington, Government Printing Office, 1925. Price, twenty-five cents. Technologic Papers, No. 302, Investigation of Synthetic Tanning Material, by Edward Wolesensky. 45 pages, 8vo. Washington, Government Printing Office, 1925. Price, fifteen cents.

Ontario Department of Mines. Thirty-fourth annual report, being vol. 34, part vi, 1925. Gold Deposits, by E. L. Bruce, and Gold Areas, by F. L. Finley and T. L. Gledhill. 106 pages, illustrations, plates, maps, 8vo. Toronto, King's Printer, 1925.

School of Mines and Metallurgy, University of Missouri. Bulletin March,

1926, Catalogue, 1925–1926. 187 pages, illustration, map, 8vo. Rolla, University, 1926.

National Advisory Committee for Aeronautics: Technical Notes, No. 231, The Resistance to the Steady Motion of Small Spheres in Fluids, by R. A. Castleman. 12 pages, illustrations, quarto. Washington, Committee, 1926.

Daniel Guggenheim Fund for the Promotion of Aeronautics. Pamphlet number two. Tentative report on program. 19 pages, 8vo. New York, 1926.

Udometria Venezolana. El regimen de la lluvia en Venezuela años de 1923 y 1924, por Ernesto Sifontes, director de la Estación Meteorológica de Ciudad Bolivar. 14 pages, 8vo. Caracas, 1925.

Anthropological Measurements and Physical Examinations of Members of Congress, by Arthur MacDonald. 4 pages, 8vo. Reprint from *The Medical Times,* February, 1926.

Rayon Silk Production. (Commerce Reports, March 22, 1926.)—The rapid development of rayon (artificial silk) manufacturing in the United Kingdom, where its progress has been particularly striking in the last two years, was given a further impetus in 1925 by the imposition of import duties on silk and rayon and manufactures thereof, effective July 1. Reliable estimates place the 1925 production of rayon in Great Britain at 30,000,000 to 32,000,000 pounds—an increase of 25 to 33 per cent. over the 1924 output of approximately 24,000,000 pounds. The increase in British rayon production closely parallels the rapid expansion and growth of the rayon industry and trade throughout the world.

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